UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

UPC - UNQ

Internet of Things

Jordi Casademont
jordi.casademont@upc.edu

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

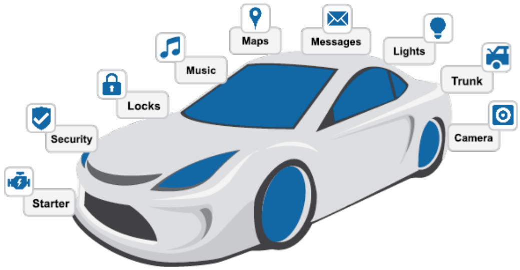
Jordi Casademont

- PhD in Telecommunications Engineering
- Professor at the Universitat Politècnica de Catalunya
  - Escola Tècnica Superior de Telecomunicació de Barcelona (ETSETB)
    - Vice-Dean Head of Master Studies
    - Director of Master in Telecommunications Engineering
    - Director of the “Grau en Enginyeria Telemàtica” (2009-2012)
  - Network Engineering Department
    - Director of the department (2003-2006)
  - Wireless Network Group
- Expertise
  - Wireless Local Area Networks: 802.11, 802.15.4
  - Internet Protocols
  - Vehicular Networks: 802.11p, Intelligent Transport Systems

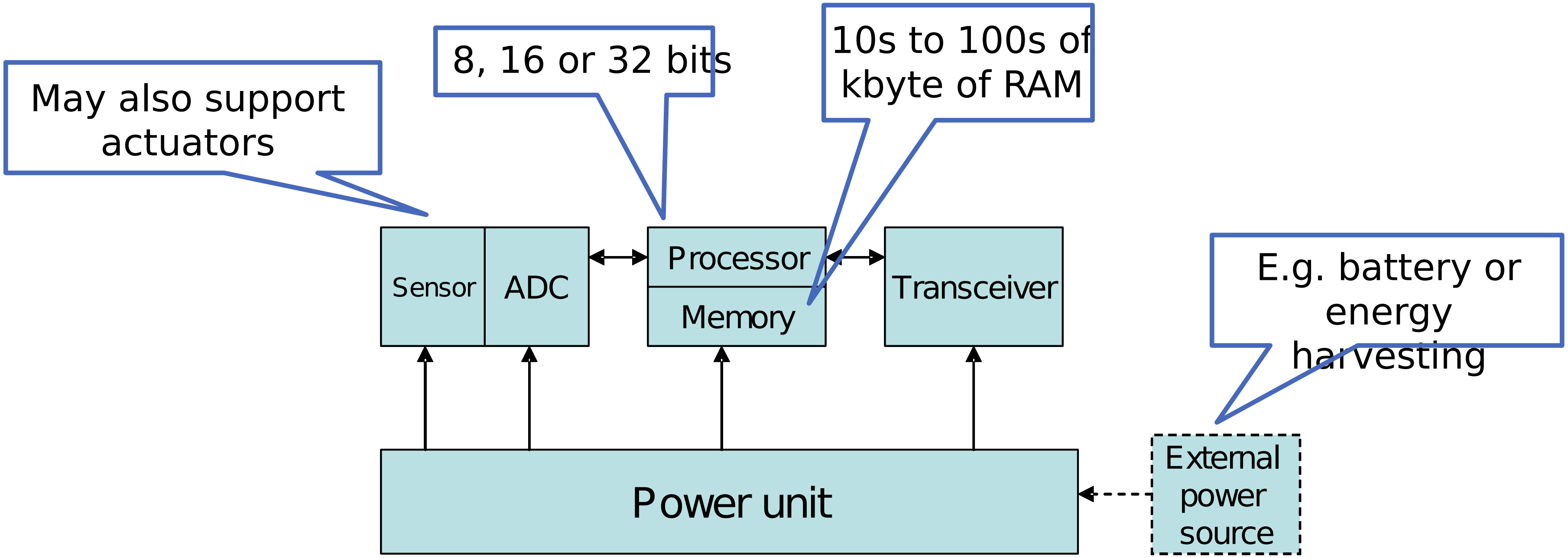
Internet of things

- Definition:
  - The Internet of Things is a network of connected devices which communicate over the Internet, and they do so autonomously, machine to machine, without the need for human intervention

Internet of Things



IoT device



- Resource constraints
  - Small size often practical (e.g. to avoid altering the associated object)
  - Sufficient for the tasks to be done
  - Economic feasibility

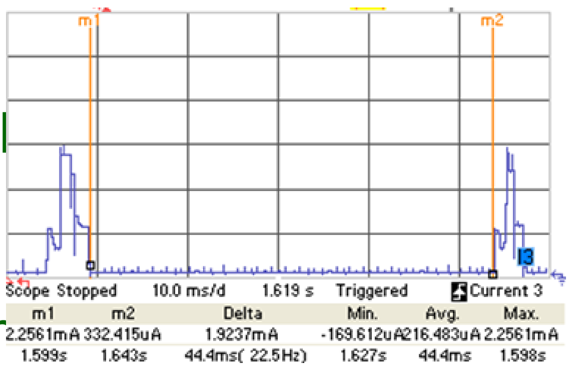
IoT device

- Energy limitations
  - Example
    - Typical current consumption of a constrained node platform
    - Cell coin battery of 230 mAh

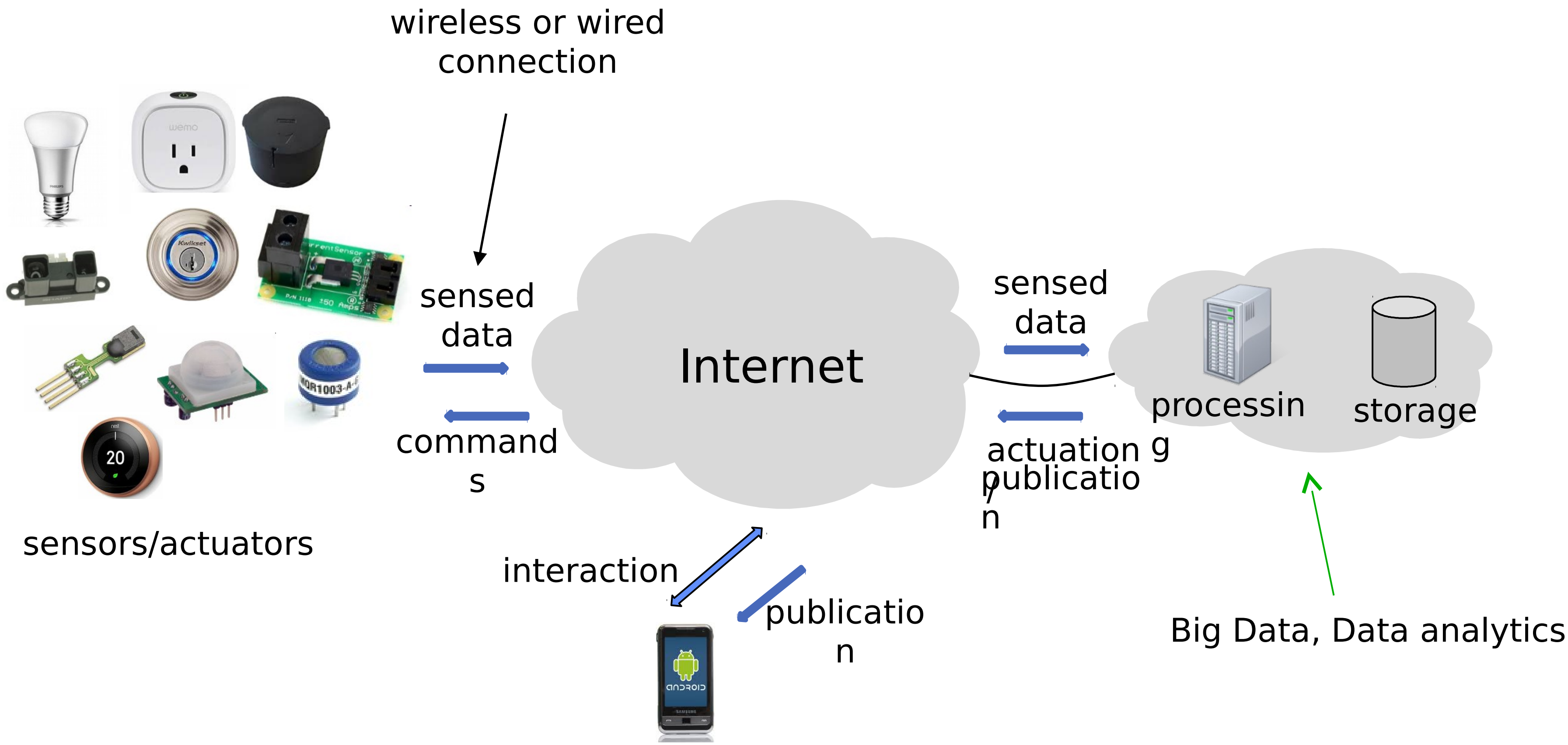
Theoretical

	Current consumption	Lifetime
Active (Tx/Rx) mode	20 mA	11.5 hours
Sleep mode	1 µA	26.25 years

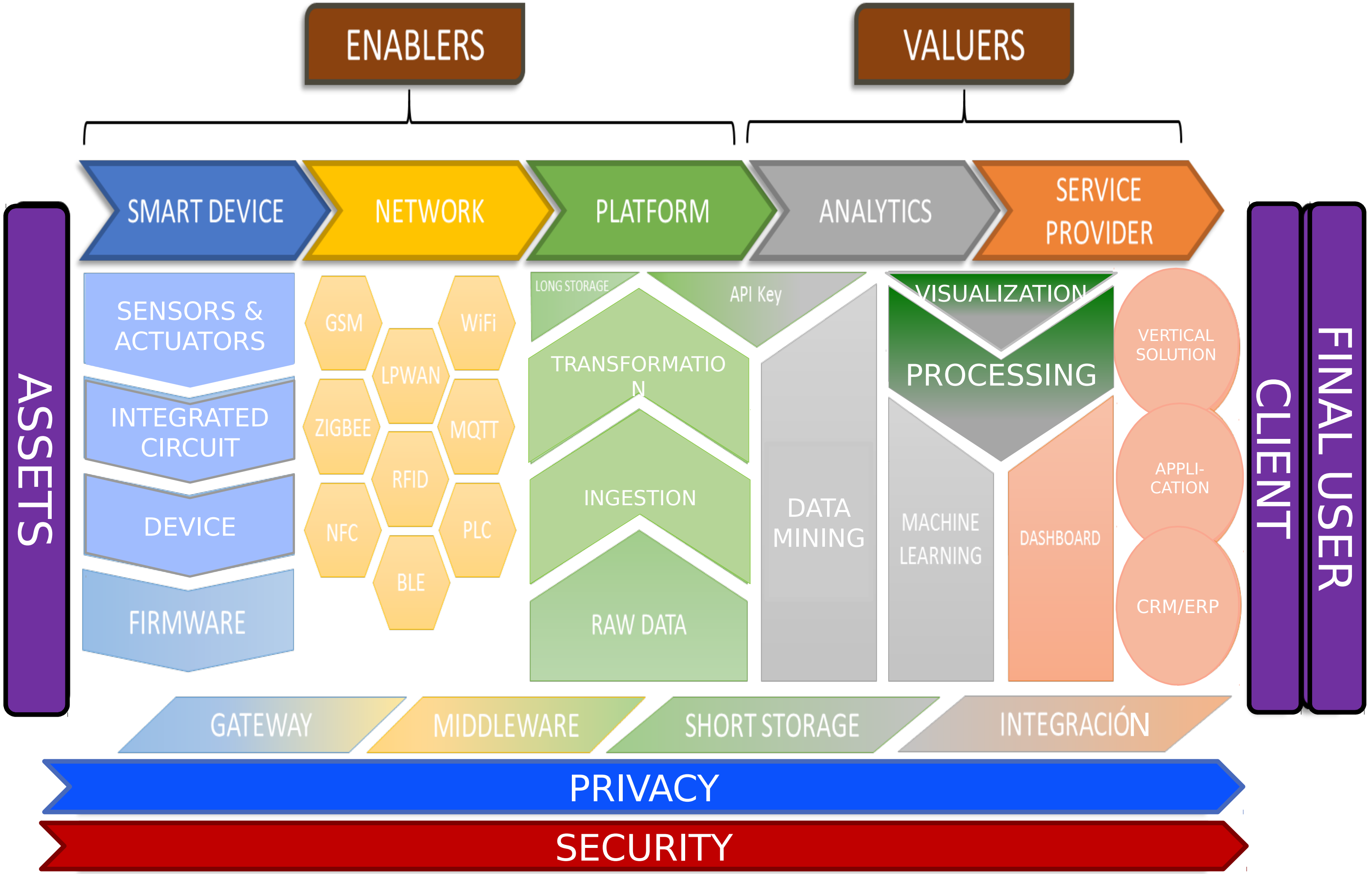
  - Fundamental concern affecting the deployment of constrained node protocols
  - Main technique: radio duty cycling



IoT ecosystem



IoT value chain



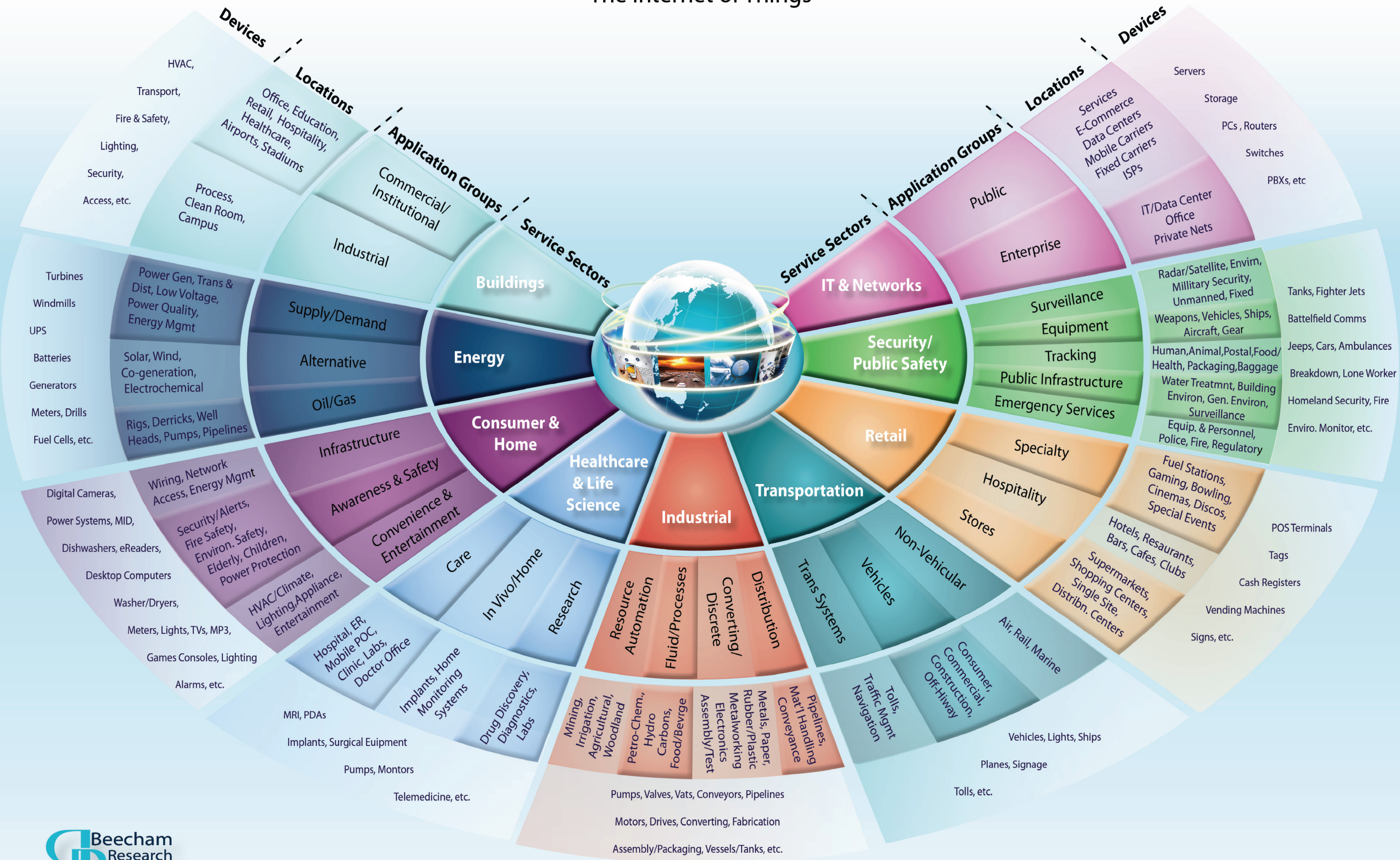
IoT: business

- Business opportunities
  - Improving existing products
  - New products
  - New ways to sell products
  - Selling "things" → selling services
  - Capitalizing information

- > 1 trillion $ market
  - By 2020 (IDC forecast)

M2M World of Connected Services

The Internet of Things

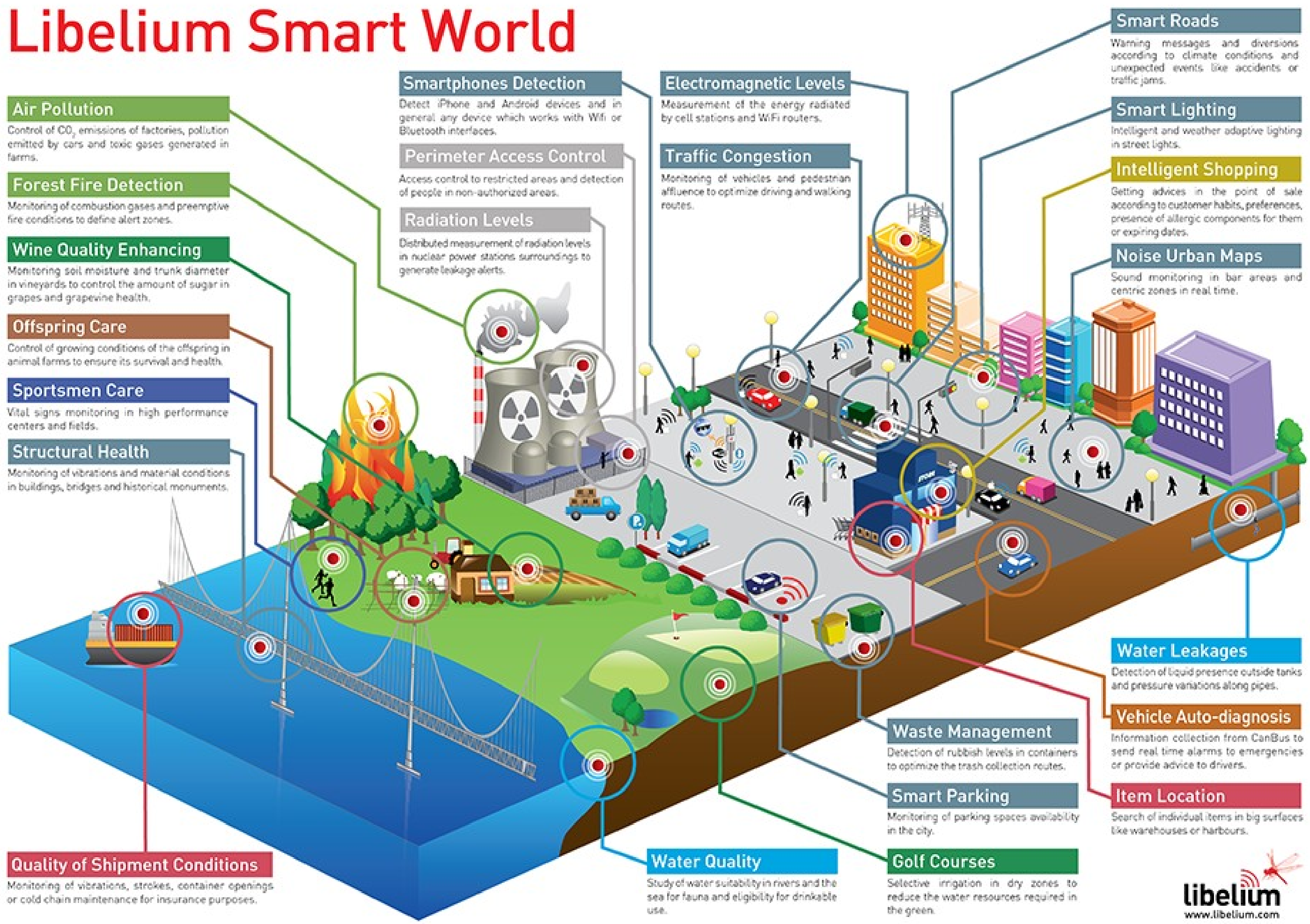


Beecham Research

Boston | London

info@beechamresearch.com +44 (0)845 533 1758 www.beechamresearch.com

IoT Applications



http://www.libelium.com/resources/top_50_iot_sensor_applications_ranking

Home automation

- Intelligent thermostats: Nest Learning Thermostat ($249)
  - 802.11, 802.15.4, BLE
- Temperature / humidity sensors
  - ATIM works with:
    - Sigfox
    - LoraWan
    - Local Modbus
  - Enless Wireless

Temperature transmitter

Domotic & Home Automation

53 Energy and Water Use
Energy and water supply consumption monitoring to obtain advice on how to save cost and resources.

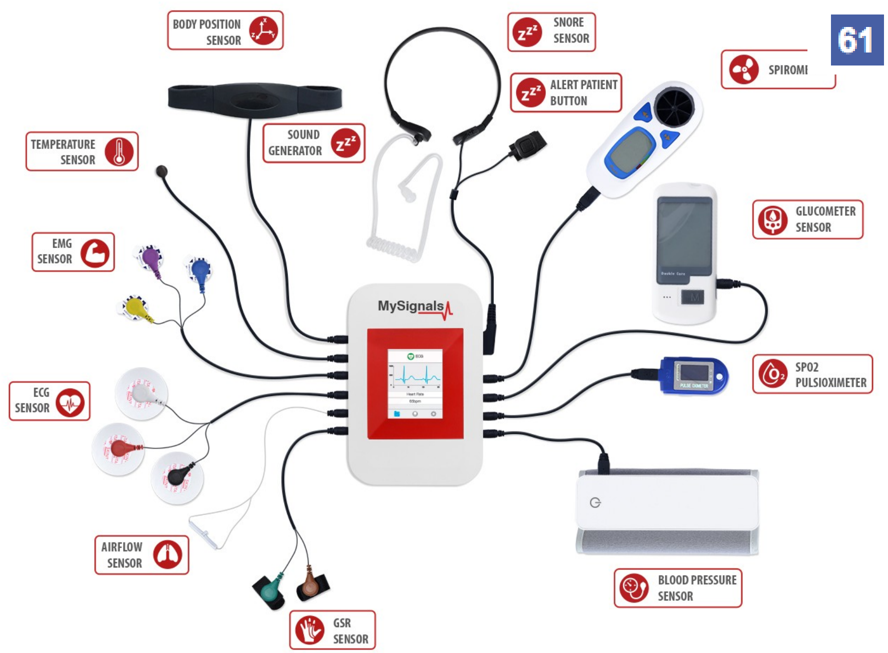
54 Remote Control Appliances
Switching on and off remotely appliances to avoid accidents and save energy.

55 Intrusion Detection Systems
Detection of windows and doors openings and violations to prevent intruders.

56 Art and Goods Preservation
Monitoring of conditions inside museums and art warehouses.

Smart health

- Libelium MySignals



eHealth

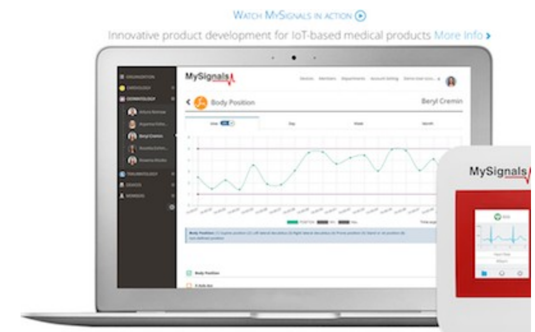
57 **Fall Detection**
Assistance for elderly or disabled people living independent.

58 **Medical Fridges**
Control of conditions inside freezers storing vaccines, medicines and organic elements.

59 **Sportsmen Care**
Vital signs monitoring in high performance centers and fields.

60 **Patients Surveillance**
Monitoring of conditions of patients inside hospitals and in old people's home.

61 **Ultraviolet Radiation**
Measurement of UV sun rays to warn people not to be exposed in certain hours.



- Sport monitoring

Smart cities

- Libelium and Urbiotica

Smart Cities

01 **Smart Parking**
Monitoring of parking spaces availability in the city.

02 **Structural health**
Monitoring of vibrations and material conditions in buildings, bridges and historical monuments.

03 **Noise Urban Maps**
Sound monitoring in bar areas and centric zones in real time.

04 **Smartphone Detection**
Detect iPhone and Android devices and in general any device which works with WiFi or Bluetooth interfaces.

05 **Eletromagnetic Field Levels**
Measurement of the energy radiated by cell stations and and WiFi routers.

06 **Traffic Congestion**
Monitoring of vehicles and pedestrian levels to optimize driving and walking routes.

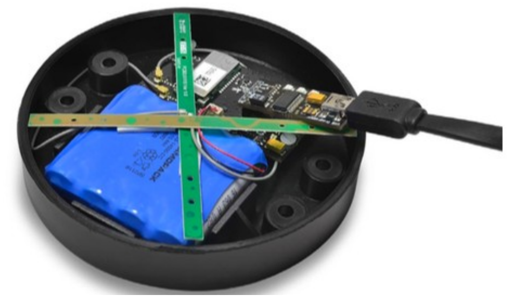
07 **Smart Lighting**
Intelligent and weather adaptive lighting in street lights.

08 **Waste Management**
Detection of rubbish levels in containers to optimize the trash collection routes.

09 **Smart Roads**
Intelligent Highways with warning messages and diversions according to climate conditions and unexpected events like accidents or traffic jams.

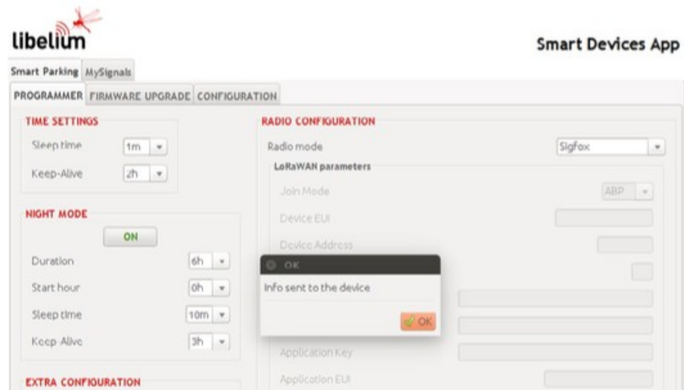
Smart cities

- Smart parking

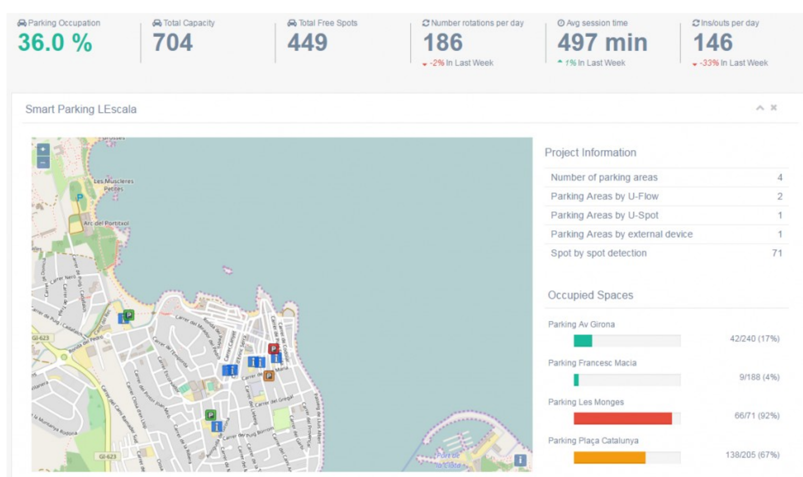


Configuration / Commissioning

Urbiotica – 802.15.4

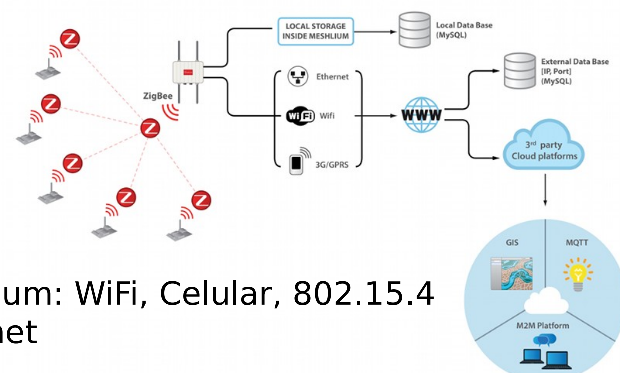


Reset with a magnet



Smart cities

- Noise and other parameters monitoring



Meshlium: WiFi, Celular, 802.15.4
Ethernet

Sensors:

- Noise / Sound Level Sensor (dBA / LeqA) + Calibration Tests
- Particle Matter (PM1 / PM2.5 / PM10) - Dust Sensor
- Carbon Monoxide (CO) [Calibrated] (low and high concentrations)
- Carbon Dioxide (CO_2) [Calibrated]
- Molecular Oxygen (O_2) [Calibrated]
- Ozone (O_3) [Calibrated]
- Nitric Oxide (NO) [Calibrated] (low concentrations)
- Nitric Dioxide (NO_2) [Calibrated] (high accuracy)
- Sulfur Dioxide (SO_2) [Calibrated] (high accuracy)
- Ammonia (NH_3) [Calibrated] (low and high concentrations)
- Methane (CH_4) [Calibrated] – and other combustible gases

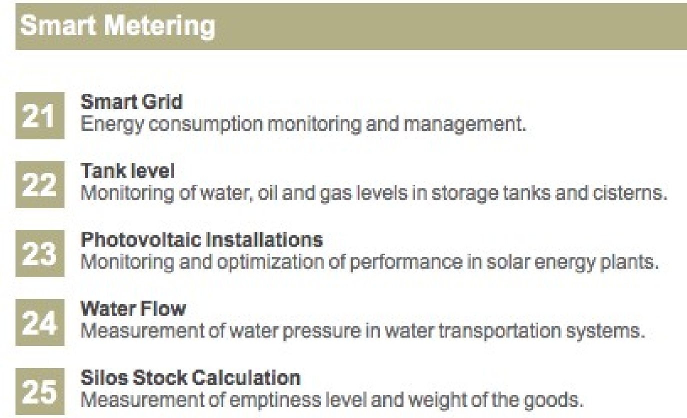
Smart cities

- Price: €5200

- Price: €2850

- https://www.the-iot-marketplace.com

Smart metering


Smart Metering

21 **Smart Grid**
Energy consumption monitoring and management.

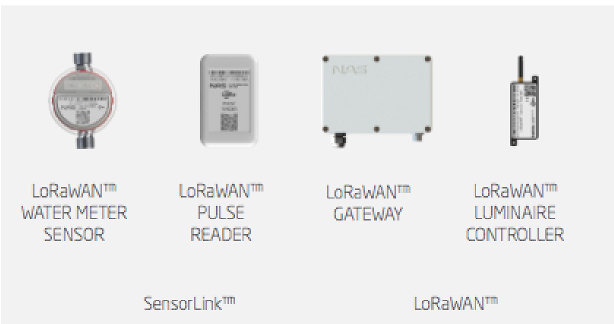
22 **Tank level**
Monitoring of water, oil and gas levels in storage tanks and cisterns.

23 **Photovoltaic Installations**
Monitoring and optimization of performance in solar energy plants.

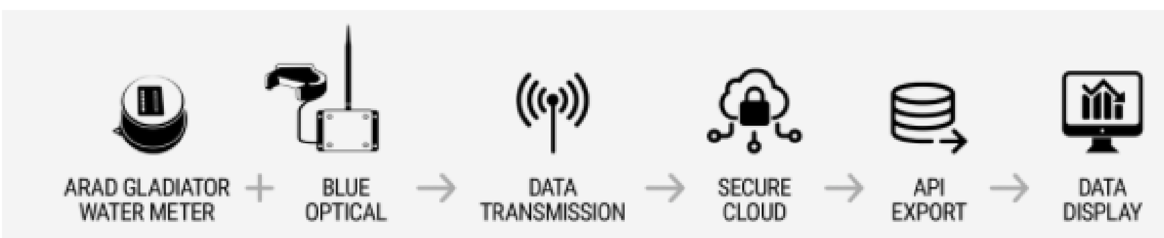
24 **Water Flow**
Measurement of water pressure in water transportation systems.

25 **Silos Stock Calculation**
Measurement of emptiness level and weight of the goods.

- NAS solution with LoraWAN



- CONNIT solution with Sigfox



- Y-RIG water meter with Sigfox

Industry 4.0

- From very complete and integral systems:
  - ABB, Bosch, …
- To very basic systems:
  - Nordic Automation Systems (NAS)
  - …
- http://www.expo21xx.com/industry4/

Industrial Control

38 **M2M Applications**
Machine auto-diagnosis and assets control.

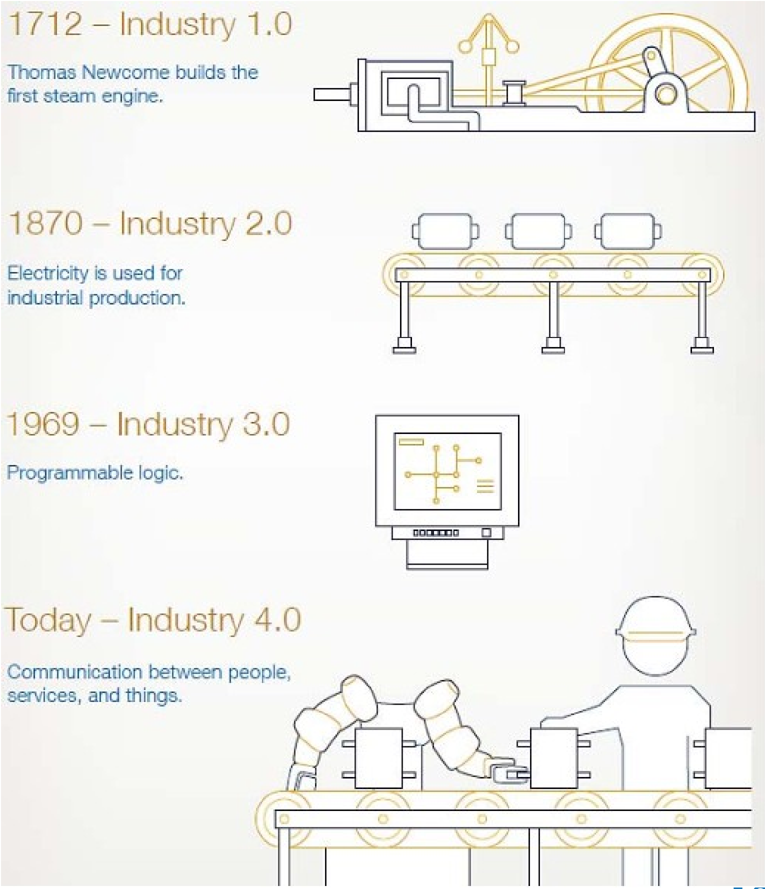
39 **Indoor Air Quality**
Monitoring of toxic gas and oxygen levels inside chemical plants to ensure workers and goods safety.

40 **Temperature Monitoring**
Control of temperature inside industrial and medical fridges with sensitive merchandise.

41 **Ozone Presence**
Monitoring of ozone levels during the drying meat process in food factories.

42 **Indoor Location**
Asset indoor location by using active (ZigBee) and passive tags (RFID/NFC).

43 **Vehicle Auto-diagnosis**
Information collection from CanBus to send real time alarms to emergencies or provide advice to drivers.



Logistics

34 **Quality of Shipment Conditions**
Monitoring of vibrations, strokes, container openings or cold chain maintenance for insurance purposes.

35 **Item Location**
Search of individual items in big surfaces like warehouses or harbours.

36 **Storage Incompatibility Detection**
Warning emission on containers storing inflammable goods closed to others containing explosive material.

37 **Fleet Tracking**
Control of routes followed for delicate goods like medical drugs, jewels or dangerous merchandises.

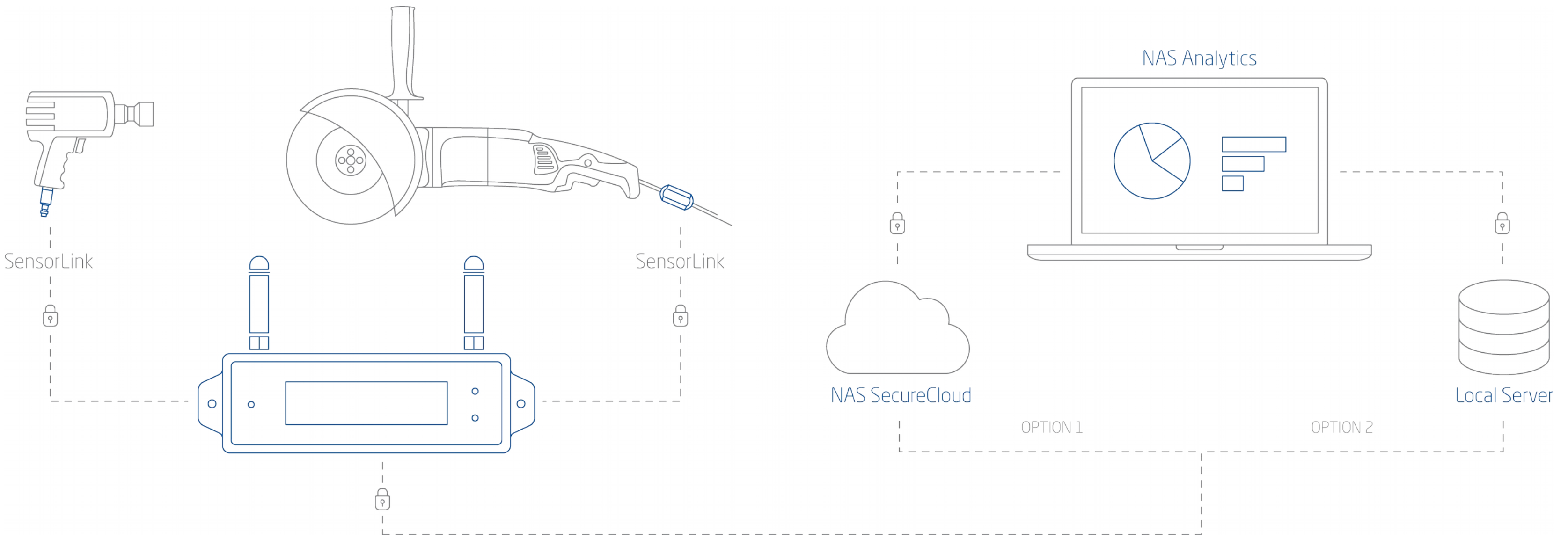
Industry 4.0

- NAS products:
  - Generic and pneumatic tool sensors
    - Vibration monitoring
    - Presence monitoring
    - Tool identification and inventory management
    - Air supply monitoring
    - Battery lifetime up to 2 years
    - Bluetooth Low Energy

  - Gateway: Cellular, Ethernet, Modbus

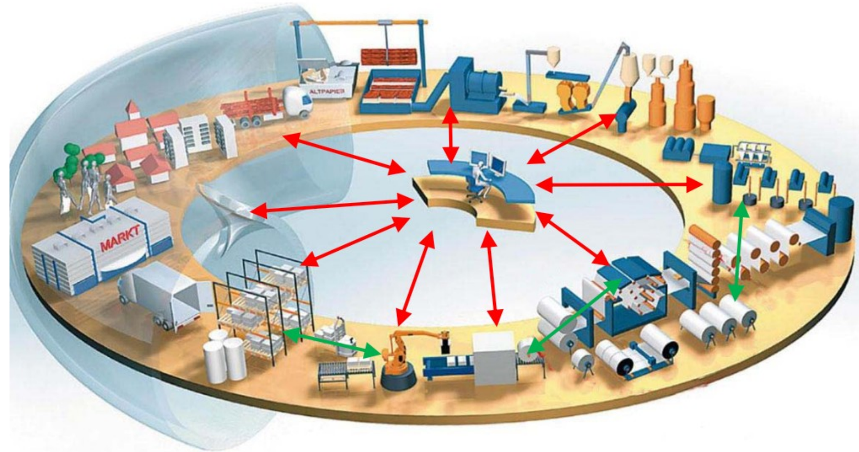
Industry 4.0

- NAS solution
  - Reduce production costs
  - Prolong lifetime of tools
  - Protect employees
  - Usage statistics and inventory

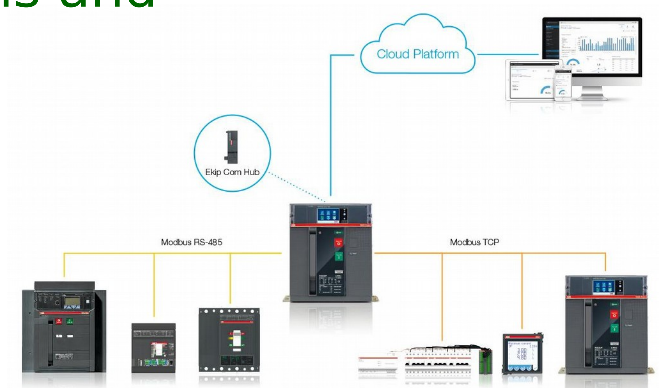


UPC - UNQ

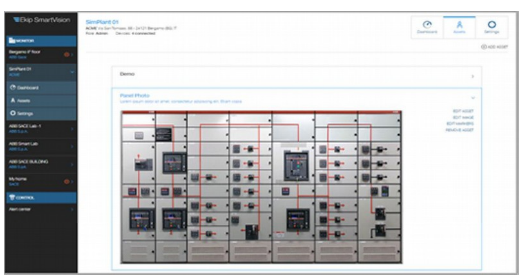
Industry 4.0



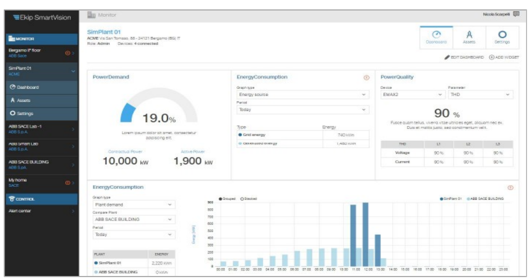
- ABB Ability
  - Pack of more than 180 solutions and services



Monitor



Optimize



Control

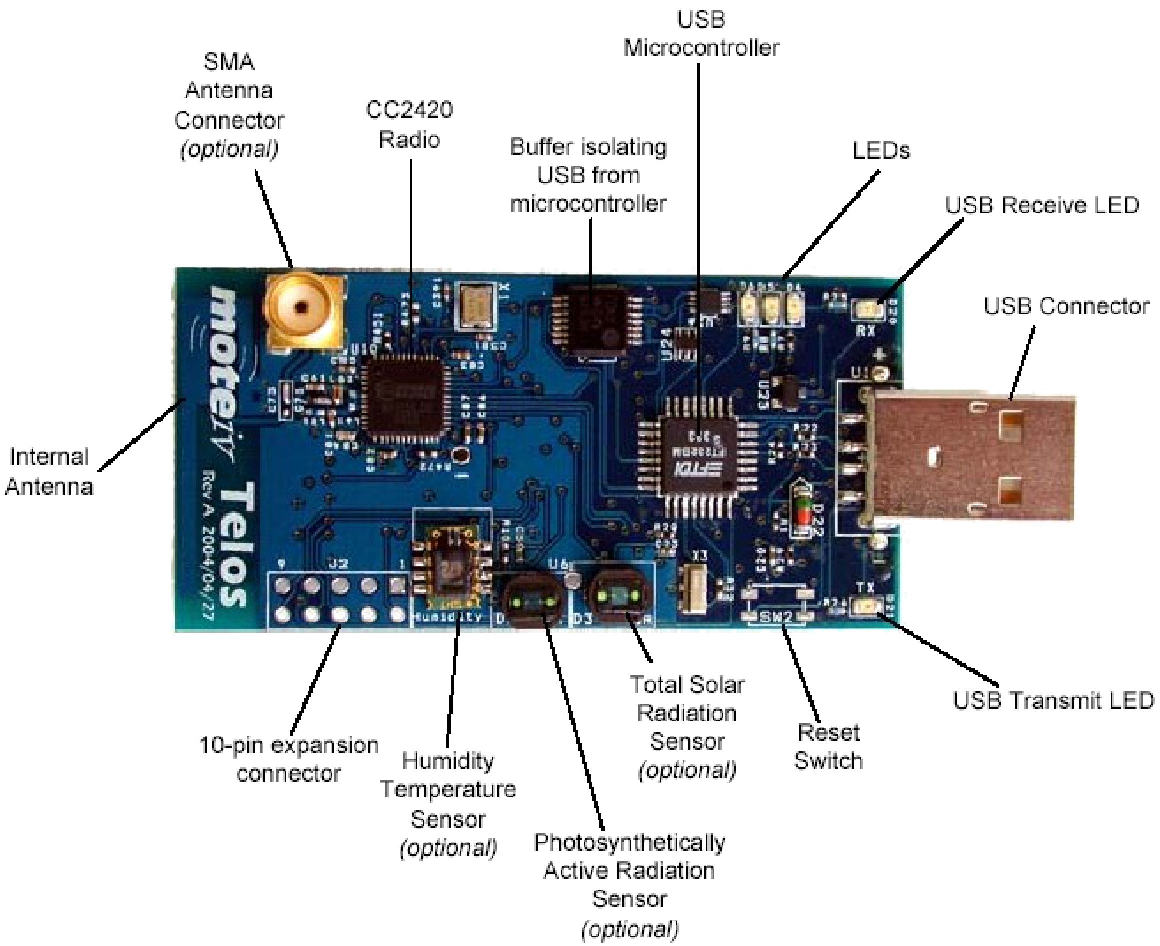
Sensors and actuators

Origins

- Based on a open hardware project from University of California that results in TelosB motes, Tmote SKY, TelosIV, ...
- Later manufactured by
  - Crossbow
  - MaxFor
    - Distributed by Advantic
  - Memsic
  - Zolertia (Made in Barcelona)
    - Z1

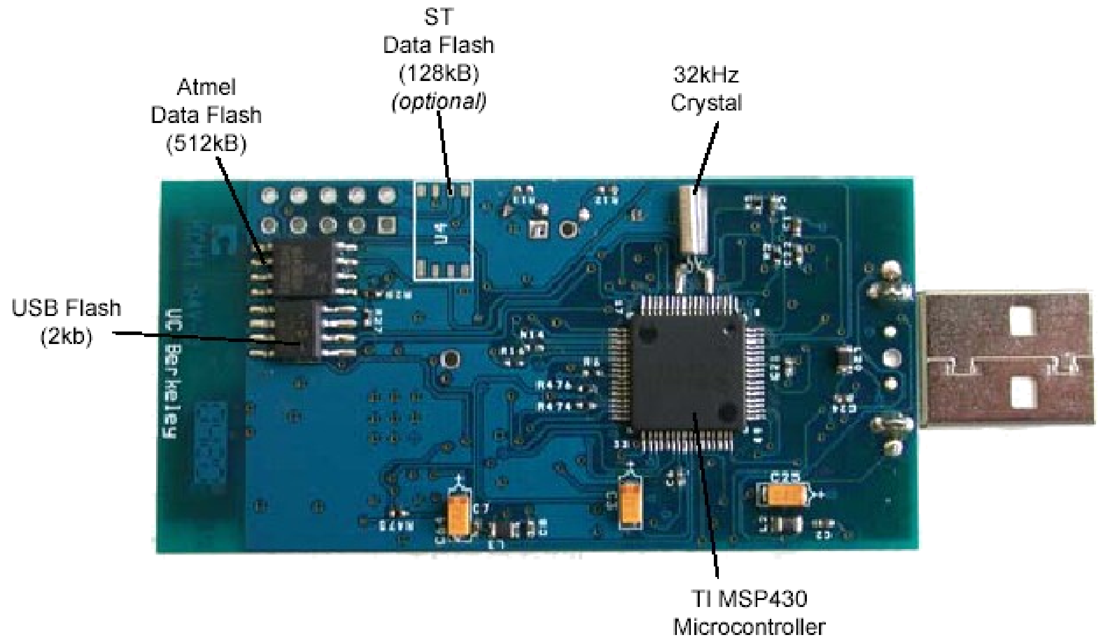
Sensor board components

- Example: TELOS mote



Sensor board components

- Example: TELOS mote



Operating systems

- TinyOS
- FreeRTOS
- RETOS
- mC/OS II
- AMBIENT RT
- Nano-Qplus
- Contiki
- …

The “Linux” of sensor node OS

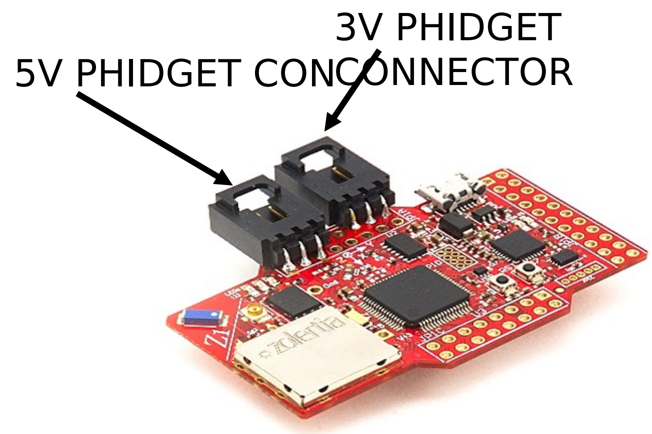
Integrated with mIP stack

https://www.postscapes.com/internet-of-things-software-guide/

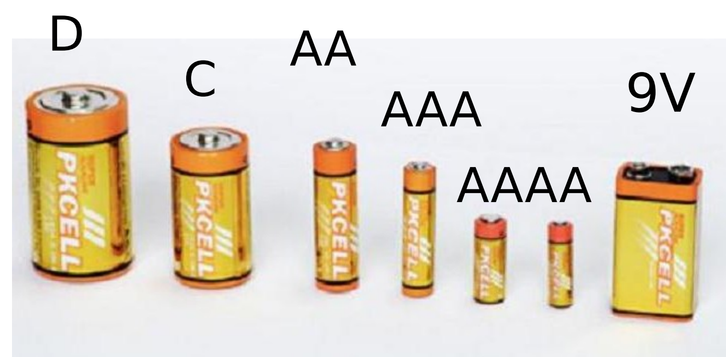
Z1 Power consumption

	IC	Operating Range	Current Consumption	Notes
MCU	MSP430f2617	1.8V to 3.6V	0.1µA 0.5µA 0.5mA < 10mA	OFF Mode Standby Mode Active Mode @1MHz Active Mode @16MHz
Radio	CC2420	2.1V to 3.6V	<1µA 20µA 426µA 18.8mA 17.4mA	OFF Mode Power Down IDLE Mode RX Mode TX Mode @ 0dBm
Accelerometer	ADXL345	1.8V to 3.6V	0.1µA 40uA to 145uA	Standby Active Mode
Flash	M25P16	2.7V to 3.6V	1µA 4mA to 15mA	Deep Power Down Active Mode
Temperature Sensor	TMP102	1.4V to 3.6V	1µA 15µA	Shutdown Mode Active Mode

Powering



- Using USB
  - 5 Volts
- Using batteries
  - 2 * 1,5 V AA
    - With batteries lower that 2,1V the radio is not working
- Batteries:
    - Examples
    - Button 250 mAh (3 V)
    - AA 2000 mAh (1,5 V)
    - AAA 1000 mAh (1,5 V)
    - 9V   500 mAh

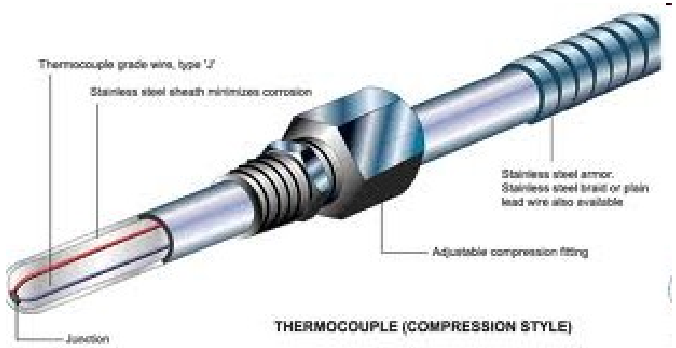


Parts of a sensor

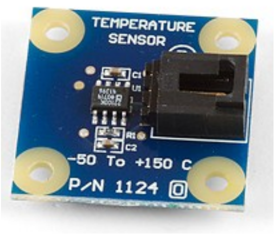
- Confusion between sensor and transducer, so we will assume a sensor is made of:
  - Transducer
    - Converts a physical magnitude to an electrical parameter
  - Signal conditioning circuit
    - In some cases it is not used
    - Adapts the electrical signal to something that can be easily used, such a ADC
      - Minimizes the noise
      - Enhances the signal range
      - Linearizes the response
      - Compensates the response in front of other variations such voltage, temperature, …

Temperature

- Thermistor
  - Resistance that varies with temperature
- Thermocoupler
  - Junction of different metals
- Infrared
  - Allows distance measurement
    - Range from -70ºC to +380ºC
    - Accuracy: 0.5ºC



- http://www.phidgets.com

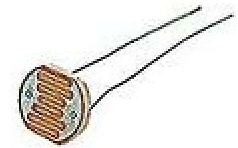


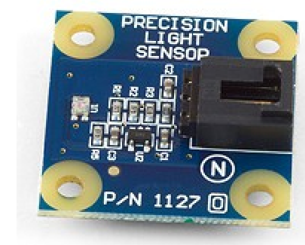
Air humidity (hydrometer)

- Measures the relative humidity (RH) of the air
- Uses a resistance that varies with humidity
- Example:
  - Measuring range: 20% – 90% RH
  - Accuracy: 5%
  - Sensitivity: 1%
  - Signal collection period: 2 s

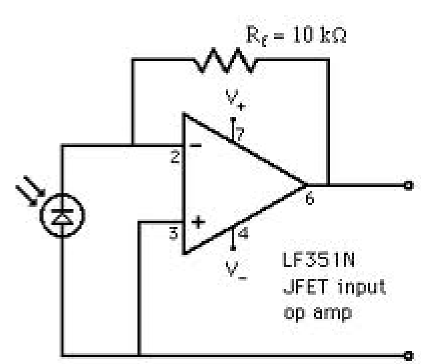
UPC - UNQ

Light



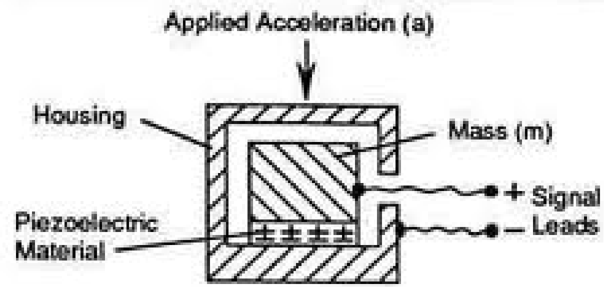


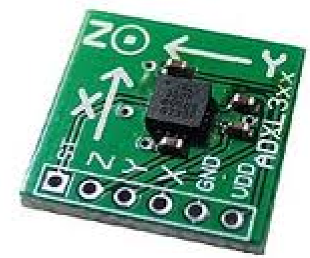
- Photodiode
  - Semiconductor device that converts light into current
  - Ligth rang:
    - 10^{-4} lux Moonless, overcast night sky (starlight)
    - 0.002 lux Moonless clear night sky with airglow
    - 0.27-1.0 lux Full moon on a clear night
    - 3-4 lux Dark limit of civil twilight under a clear sky
    - 50 lux Family living room lights
    - 80 lux Office building hallway/toilet lighting
    - 100 lux Very dark overcast day
    - 320-500 lux Office lighting
    - 400 lux Sunrise or sunset on a clear day.
    - 1,000 lux Overcast day; typical TV studio lighting
    - 10,000-25,000 lux Full daylight (not direct sun)
    - 32,000-130,000 lux Direct sunlight
- Photoresistor or light-dependent resistor (LDR) or photocell
  - It is a light-controlled variable resistor



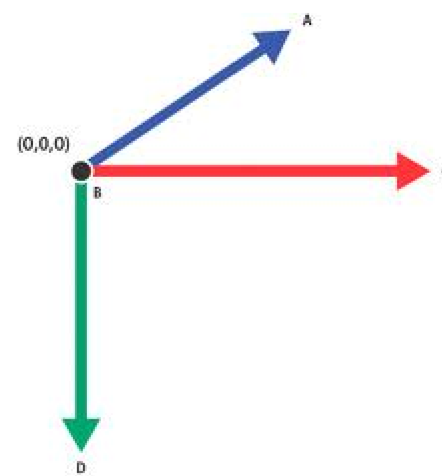
Acceleration

- Basics
  - Piezoelectric
  - Magnetic induction
  - Capacity effect



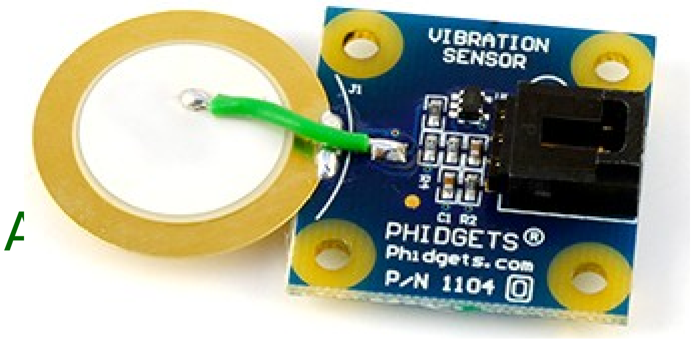


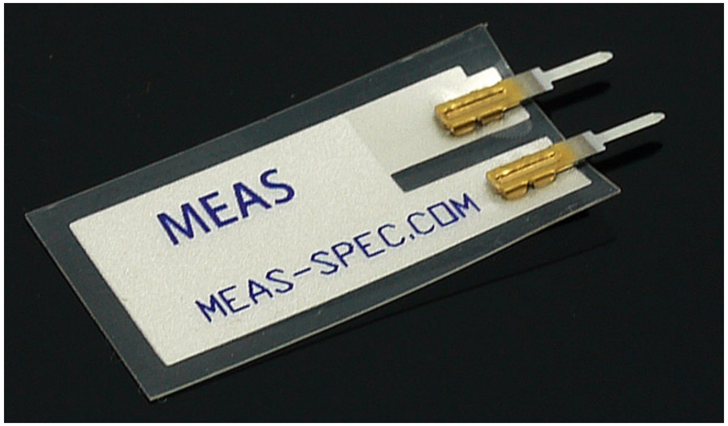
- Can be used as movement sensor
- Can be used as inclinometers using the gra
- Example:
  - 1D, 2D or 3D
  - Acceleration range in g



Vibration

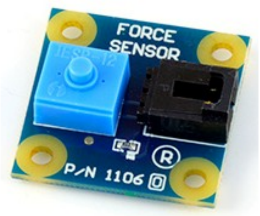
- Piezoelectric
  - Bending results in a voltage
  - Current consumption: 400 mA

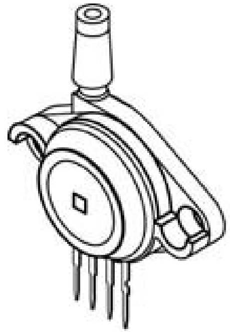


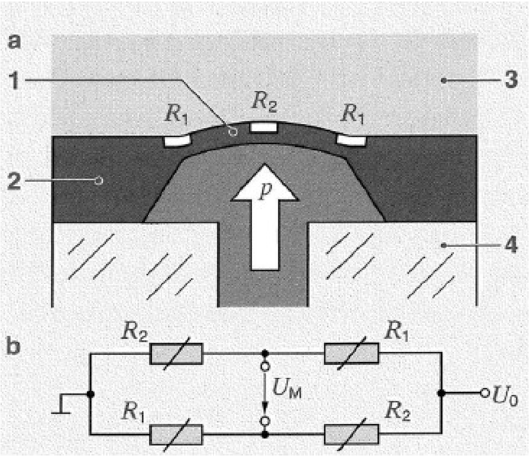


Force and pressure

- Piezoelectric
- Resistive
  - Depending of the pressure
- Pressure
  - Barometer
  - Example:
    - Minimum: -25 kPa
    - Maximum: 25 kPa
    - Response time: 1 ms

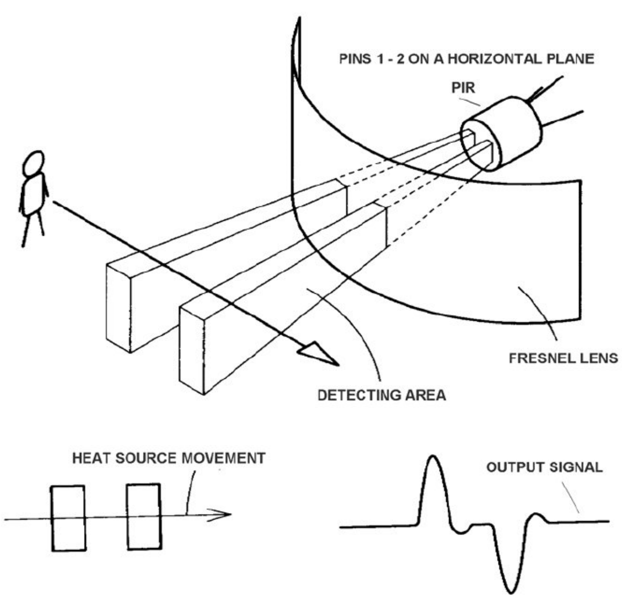


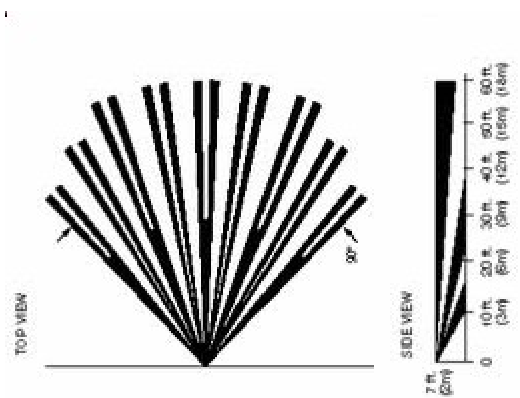




Presence

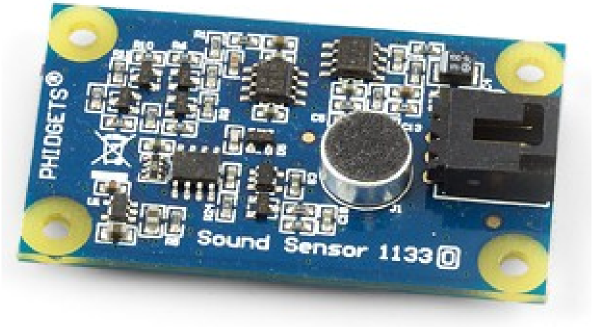
- Passive InfraRed (PIR)
  - Measures the difference of infrared signal received
  - Human bodies produce differences in temperature
  - Example:
    - Up to 5 meters for a person moving 0.5 to 1.5 m/s





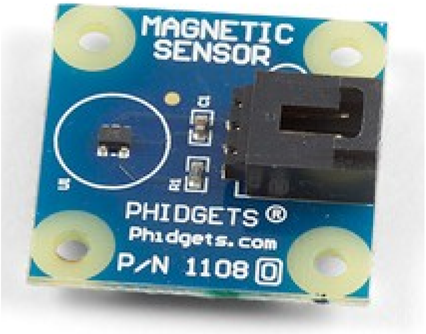
Sound

- Microphone
  - Range of frequencies (Hz)
  - Volume (dB)
  - Example:
    - Resolution: 30 mV/dB
    - Input range: 50 dB to 100 dB
    - Error (@1 kHz): 3 dB
    - Input frequency range: 100 Hz to 8 kHz



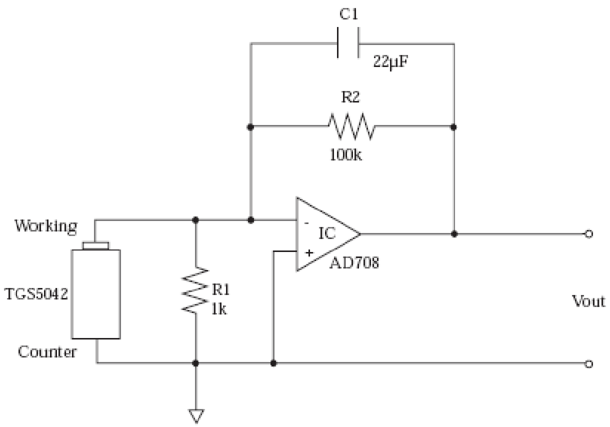
Magnetic field

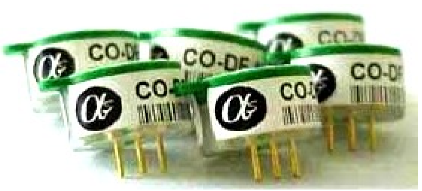
- Magnetometer
  - Measures de magnetic field strength
  - Can be used as a compass
  - Can be scalar (measuring the total magnetic field) or vector based (measuring each component of the field)



Gas

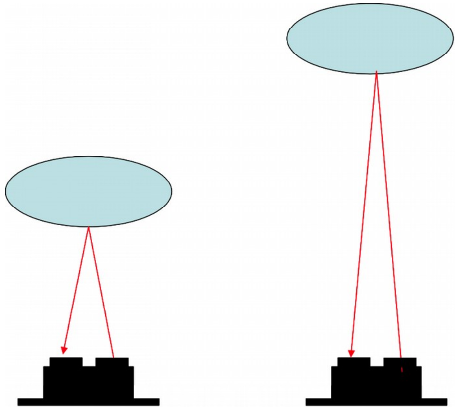
- Electrochemical
  - Results in small current from a chemical reaction
  - Needs to be replaced periodically
  - Can detect:
    - CO, CO_2, NO_2, CH_4, NH_3, O_2 or smoke





Measuring distances: Infra-red

- Infra-red reflective sensor
  - Infra-red LED + phototransistor
  - Measures distances up to 10 cm away



Measuring distances: Ultrasounds devices

- LV- MaxSonar EZ2
  - Freq. 42 kHz
  - Range up to 6.45 m

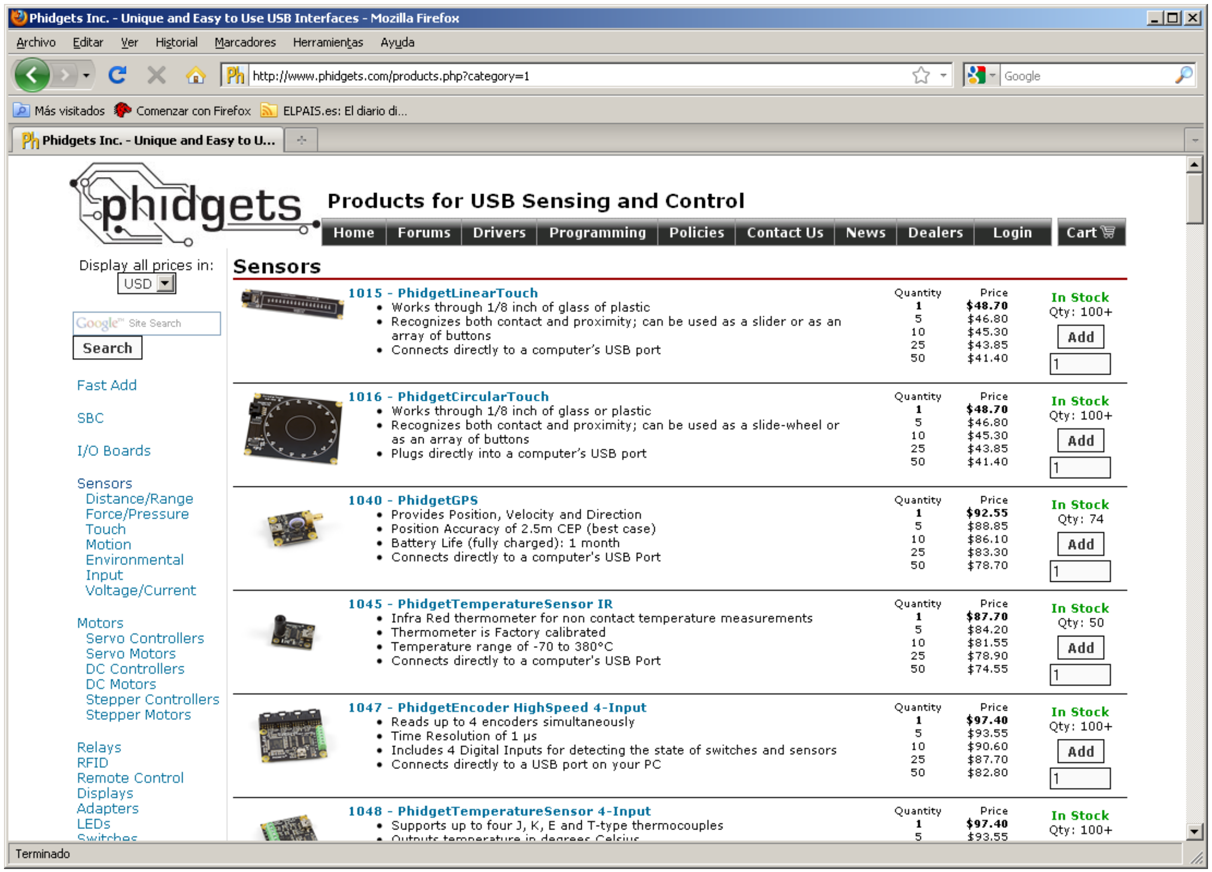
- SRF08
  - Freq. 40 kHz
  - Range up to 6 m
  - Gain adjustment
  - Able to receive several echoes
  - Power consumption: 3 mA (stand-by); 15 mA (working)
- SRF02
  - Range up to 6 m
  - 1 transductor (emission and reception)
  - Power consumption: 4 mA

Actuators

- Digital relay
  - Electric switch (mechanic)
  - Powered by 5 V and controlled by a digital signal
  - Able to control up to 7 A - 240 V AC

Sensors & Actuators

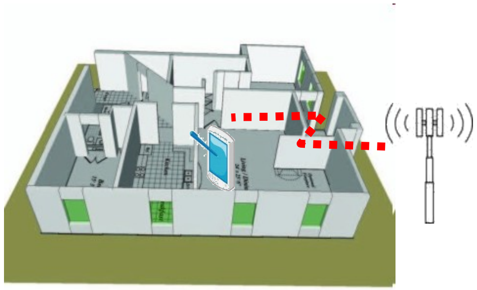
- More information
  - https://en.wikipedia.org/wiki/List_of_sensors
  - http://www.phidgets.com

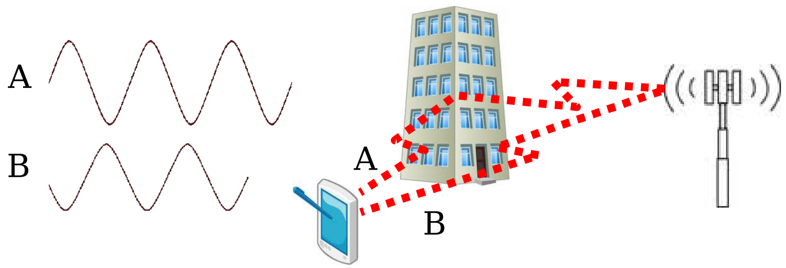


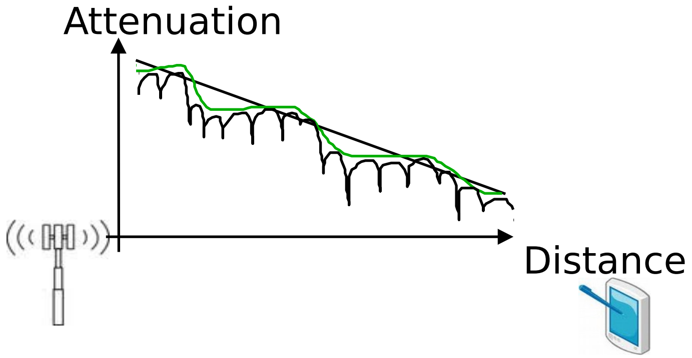
Wireless communication technologies in IoT

Communication Range

- Depends on:
  - Attenuation:
    - Frequency band
    - Environment:
      - Obstacles, foliage, buildings
      - Multipath
  - Transmitted power
  - Receiver sensitivity
  - Antenna







Relevant frequency bands

Frequency band	Availability	Applications
6.765 – 6.795 MHz	Worldwide	ISM
13.553 - 13.567 MHz	Worldwide	ISM, RFID
26.957 - 27.283 MHz	Worldwide	ISM, ham radio
40.66 - 40.70 MHz	Worldwide	ISM
433.05 - 434.79 MHz	Europe, Africa and part of Asia	ISM, RFID
865 – 868 MHz	Europe	WSN, RFID
868 – 870 MHz	Europe	Non-specific low power data devices
902 - 928 MHz	Americas, Greenland and some Pacific Islands	ISM, WPAN, cordless phones, WSN, RFID
2.400 – 2.4835 GHz	Worldwide	ISM, WLAN, WPAN, cordless phones, WSN, RFID
5.725 – 5.875 GHz	Worldwide	ISM, WLAN, cordless phones
24 – 24.25 GHz	Worldwide	ISM, Short Range Devices
59.3 – 62 GHz	Worldwide	ISM, Short Range Devices

ISM (industrial, scientific and medical) radio bands are reserved internationally for the use of radio frequency energy for industrial, scientific and medical purposes other than telecommunications
RFID (Radio-frequency identification) is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects
Ham radio or amateur radio is a radio frequency spectra for purposes of private recreation, non-commercial exchange of messages, wireless experimentation, self-training, and emergency communication
http://www.erodocdb.dk/docs/doc98/official/pdf/ERCRep025.pdf

Radio frequencies for IoT

- ISM bands
  - 433 MHz
  - 868 MHz
  - 915 MHz
  - 2,4 GHz
  - 5 GHz
  - UWB (3,6 – 10,1 GHz)
    - Ultra Wide Band

433 MHz sensor gateway

BTnode

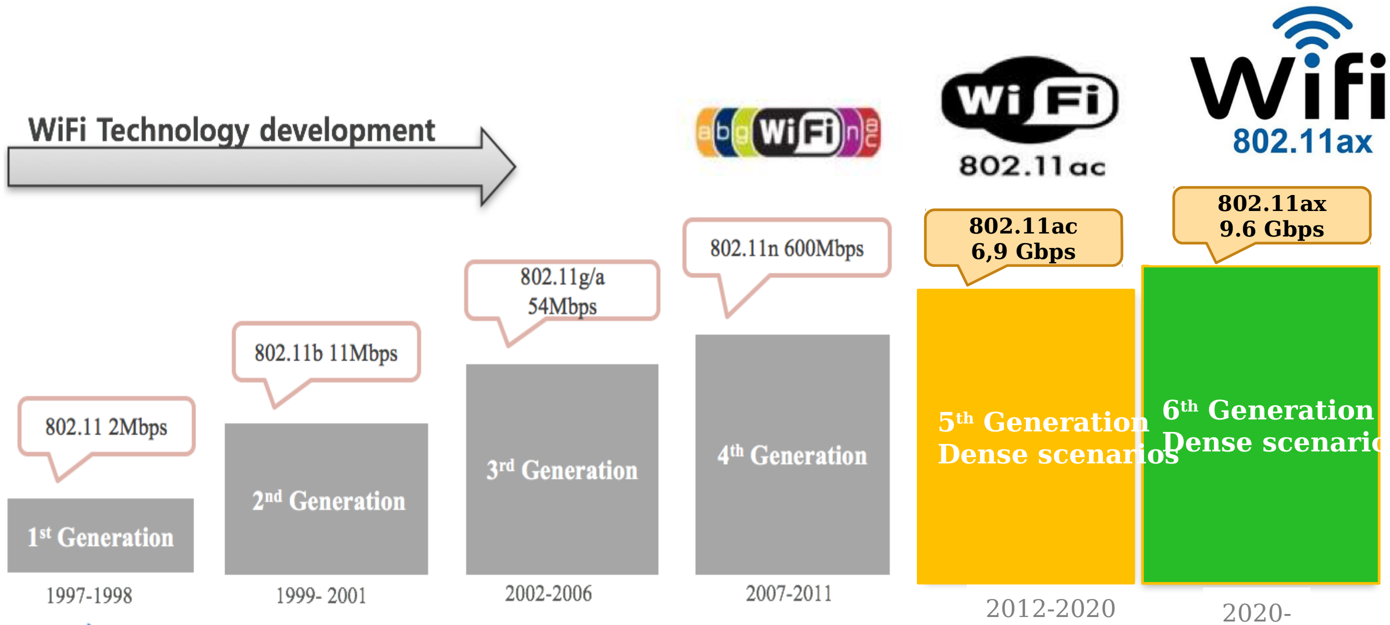
Wireless Local Area Networks: Wi-Fi (IEEE 802.11)

802.11a/b/g/n/ac
802.11ah

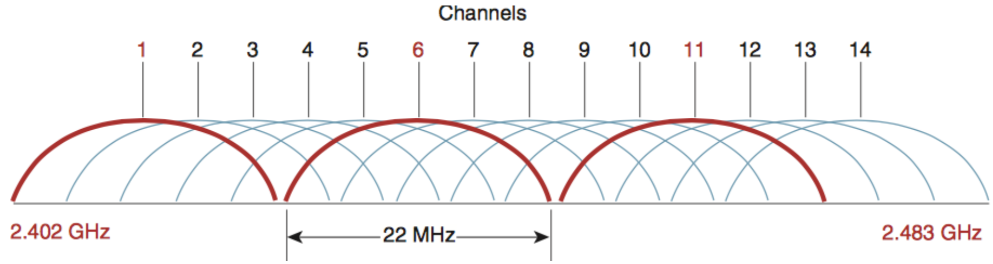
IEEE 802.11 evolution

- Partnership WECA: Wireless Ethernet Compatibility Alliance

- Nowadays called Wi-Fi Alliance



802.11 Spectrum



- ❑ 2,4 GHz
- ❑ 5 GHz

- ❑ Transmitted power
  - 2,4 GHz: 100 mW EIRP
  - 5 GHz:
    - 200 mW indoors
    - 1 W (DFS + TPC)

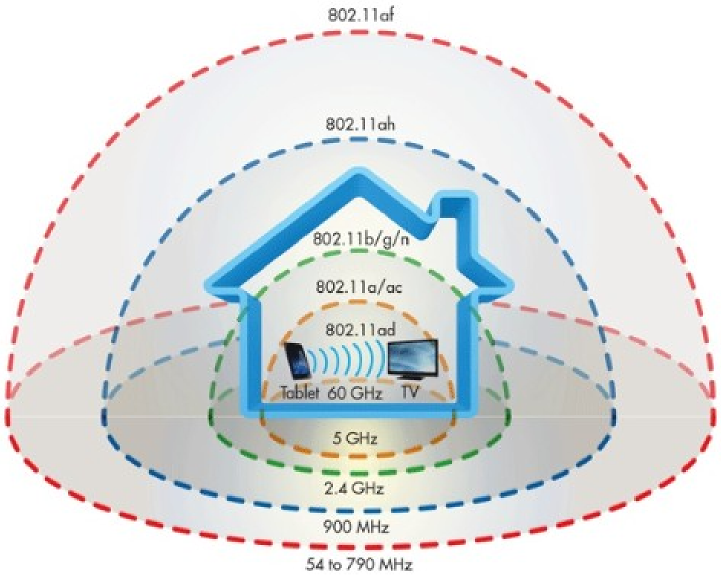
CHANNEL NUMBER	FREQUENCY MHZ	EUROPE (ETSI)	NORTH AMERICA (FCC)	JAPAN
36	5180	Indoors	✔	✔
40	5200	Indoors	✔	✔
44	5220	Indoors	✔	✔
48	5240	Indoors	✔	✔
52	5260	Indoors / DFS / TPC	DFS	DFS / TPC
56	5280	Indoors / DFS / TPC	DFS	DFS / TPC
60	5300	Indoors / DFS / TPC	DFS	DFS / TPC
64	5320	Indoors / DFS / TPC	DFS	DFS / TPC
100	5500	DFS / TPC	DFS	DFS / TPC
104	5520	DFS / TPC	DFS	DFS / TPC
108	5540	DFS / TPC	DFS	DFS / TPC
112	5560	DFS / TPC	DFS	DFS / TPC
116	5580	DFS / TPC	DFS	DFS / TPC
120	5600	DFS / TPC	No Access	DFS / TPC
124	5620	DFS / TPC	No Access	DFS / TPC
128	5640	DFS / TPC	No Access	DFS / TPC
132	5660	DFS / TPC	DFS	DFS / TPC
136	5680	DFS / TPC	DFS	DFS / TPC
140	5700	DFS / TPC	DFS	DFS / TPC
149	5745	SRD	✔	No Access
153	5765	SRD	✔	No Access
157	5785	SRD	✔	No Access
161	5805	SRD	✔	No Access
165	5825	SRD	✔	No Access

Note 2: DFS = Dynamic Frequency Selection; TPC = Transmit Power Control; SRD = Short Range Devices 25 mW max power.

IEEE 802.11 Evolution (IEEE Std 802.11-2016)

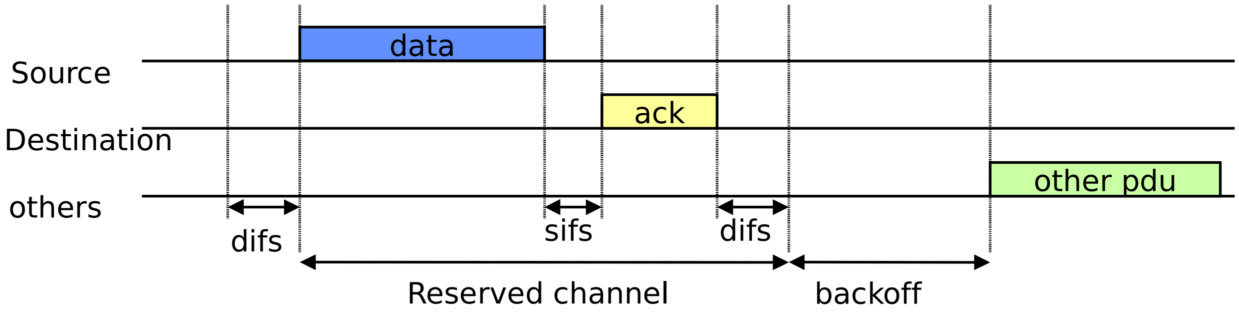
- 802.11af (2013): Television very high throughput (TVHT) – Clause 22
  - Utilization of Wi-Fi technology within unused white spaces of licensed TV spectrum (VHF and UHF bands between 54 and 790 MHz)
  - Data rates: from 1,8 Mbps to 568,9 Mbps
  - Cognitive radio and geolocation techniques to avoid interference with digital TV

- 802.11ah (2016) or HaLow:
  - Utilizes sub 1 GHz license-exempt bands to provide extended range Wi-Fi networks



802.11 – Frame Acknowledgement

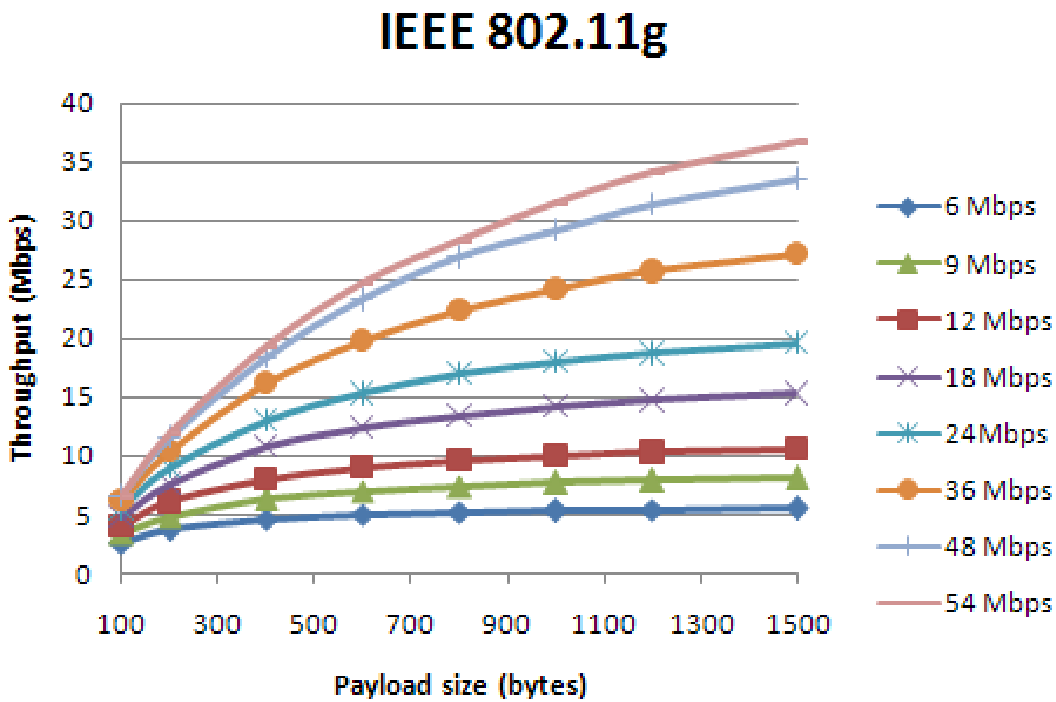
- Error control in the radio medium:
  - Acknowledgement of a correct received frame (ACK)
  - DIFS (DCF Inter-Frame Spacing): time to prioritize
  - SIFS (Short inter-frame spacing)
    - SIFS < DIFS
    - The ack has to wait less, so it has more priority
  - If the acknowledgement is not received, the station retransmits the packet but without preference in front of other stations



802.11 – Multiple Access

- Carrier Sense Multiple Access / Collision Avoidance
  - When someone wants to transmit first it listens to the channel
    - If it's free during DIFS time, it transmits
    - If it's busy waits until the transmission ends, waits DIFS time and after that enters in random backoff
  - When finishing the backoff, if the medium continues free, it transmits
  - If meanwhile is in backoff activity is detected, the timer is stopped until rest state is reached for a DIFS time and after that is reactivated
    - The timer is not reinitialized, so to avoid to harm stations that are waiting in front the ones that have arrived recently
  - When the timer expires and the channel is free, it transmits

802.11g throughput performance



Capacity in IEEE 802.11n

- Limited by the CSMA/CA MAC (DIFS, SIFS, headers, …)
    - Irreducible overhead

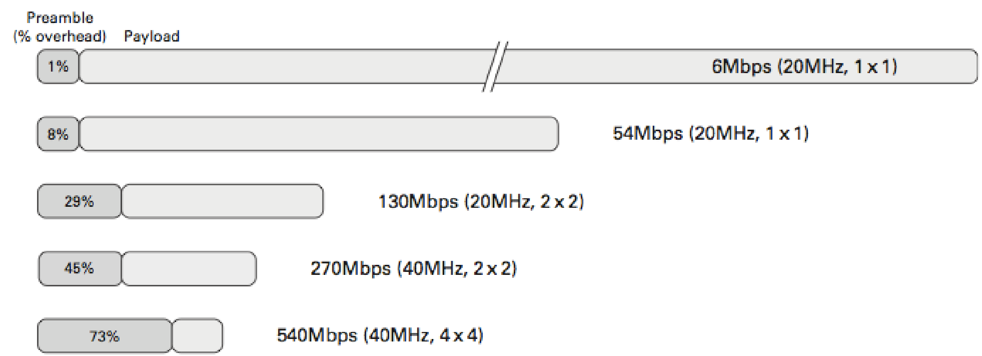
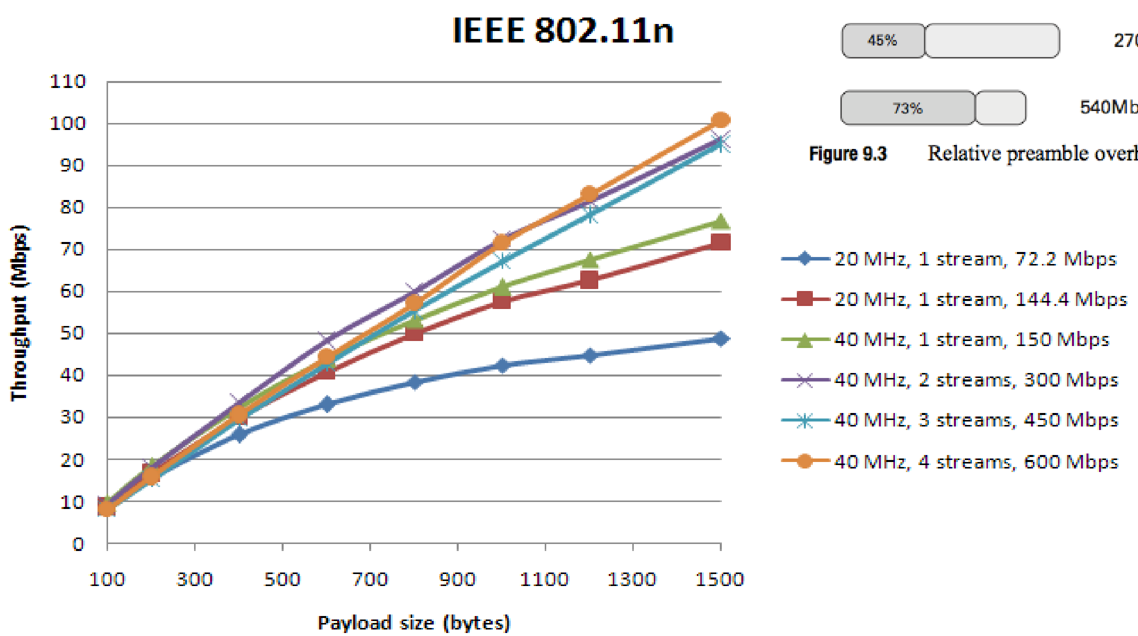


Figure 9.3 Relative preamble overhead for a 1500 byte frame at different PHY data rates.



Improvements

- Basic Throughput enhancements

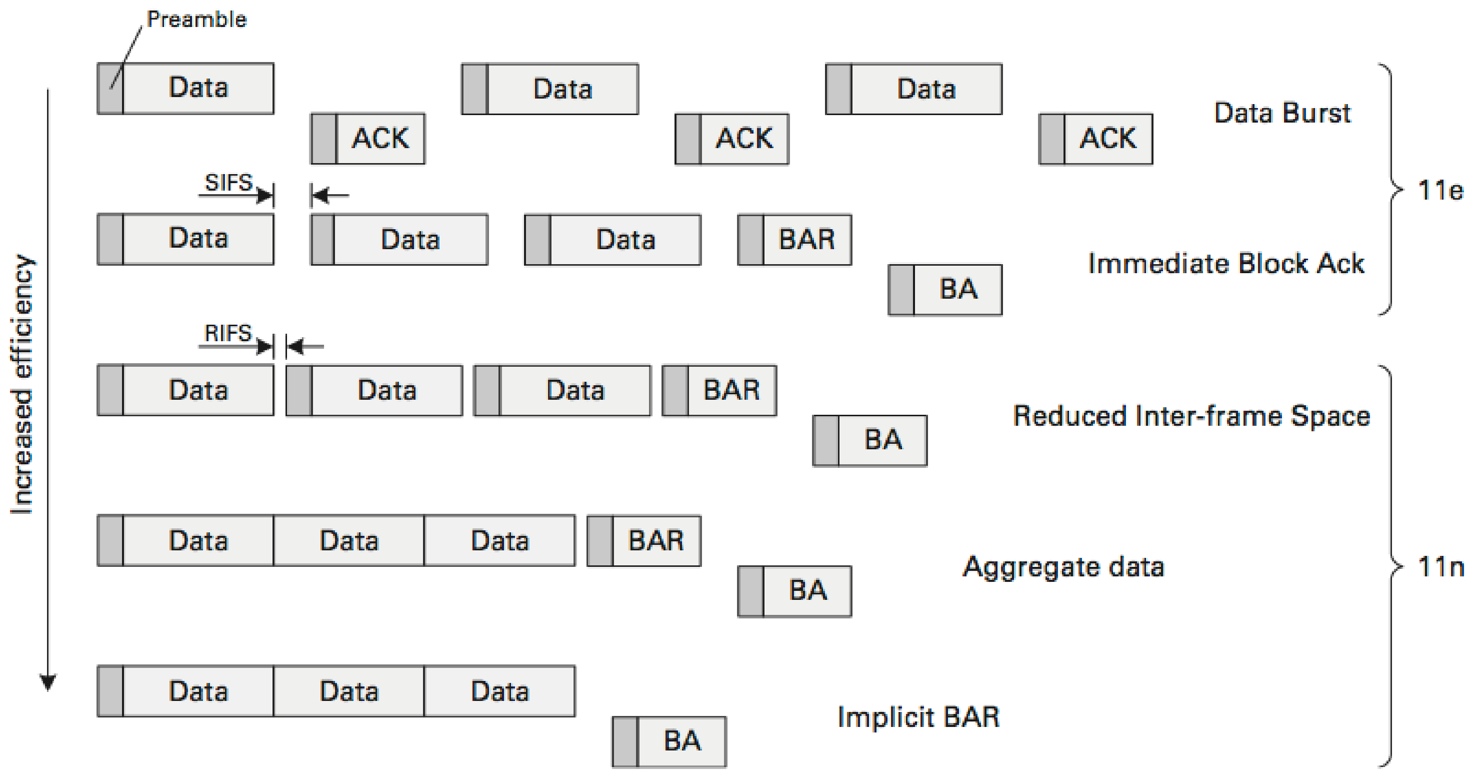


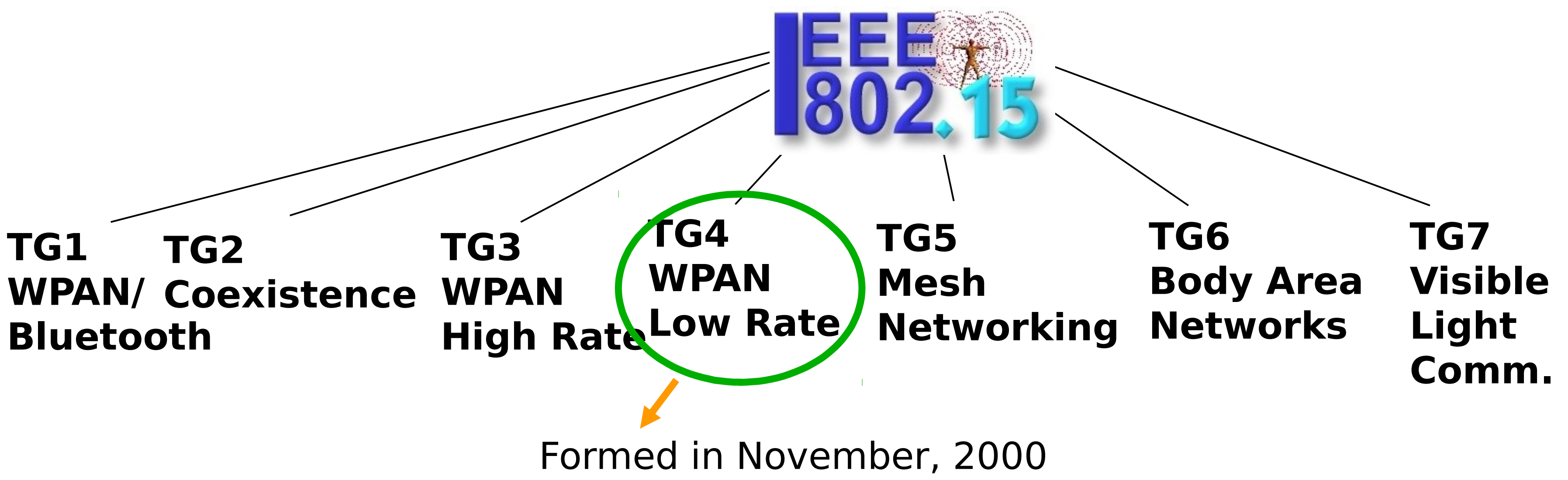
Figure 9.4 Basic throughput enhancements to the 802.11 MAC.

802.11n throughput performance

- 802.11n performance with frame aggregation of 65535 bytes and HT Greenfield Format preamble.

802.11n configuration	Throughput (Mbps)	% of nominal bit rate
20 MHz, 1 stream, 72.2 Mbps	71.44	98.9
20 MHz, 2 streams, 144.4 Mbps	141.16	97.8
40 MHz, 1 stream, 150 Mbps	146.74	97.8
40 MHz, 2 streams, 300 Mbps	286.30	95.4
40 MHz, 3 streams, 450 Mbps	414.78	92.2
40 MHz, 4 streams, 600 Mbps	539.16	89.9

Short range wireless communications



Low-Rate Wireless Personal Area Networks (LR-WPAN): IEEE802.15.4

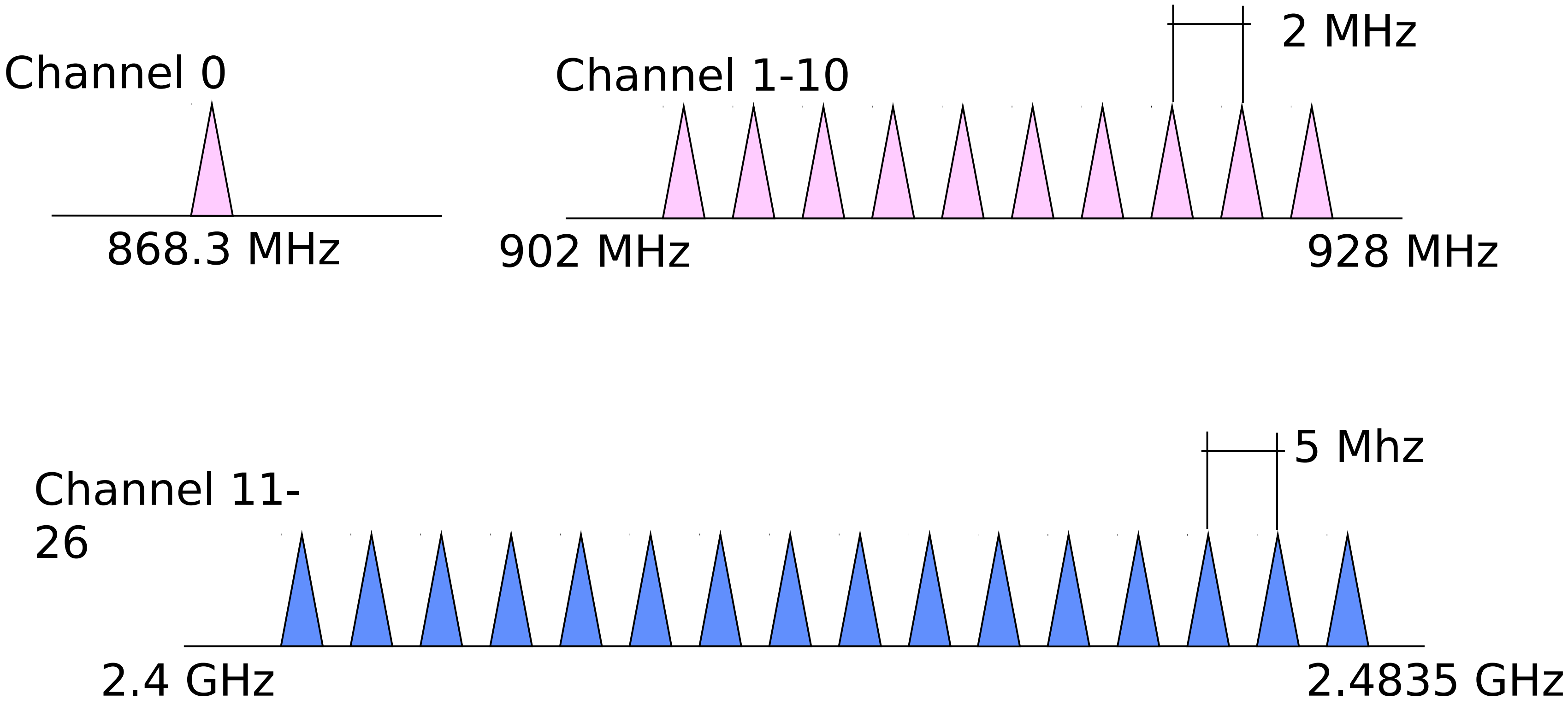
IEEE 802.15.4: Purpose

- Very low consumption
- Low complexity
- Low cost

} Networks that until now were unviable

- How to get it?
  - Few transmissions with few data
  - Very small working cycles
  - Very small headers

Physical layer



Physical layer

- IEEE 802.15.4-2003

Frequency band	Number of channels	Symbol rate (kbaud)	Modulation	Bit rate (kbps)
868 MHz	1	20	BPSK	20
915 MHz	10	40	BPSK	40
2.4 GHz	16	62.5	16-ary	250

- IEEE 802.15.4-2006: Added the following modes

Frequency band	Number of channels	Symbol rate (kbaud)	Modulation	Bit rate (kbps)
868 MHz	1	12,5	20-bit PSSS	250
915 MHz	10	50	5-bt PSSS	250
868 MHz	1	25	16-ary Orthogonal	100
915 MHz	10	62,5	16-ary Orthogonal	250

Physical layer

- IEEE 802.15.4a-2007
- 16 more channels at bands:
  - 500 MHz: subGHz
  - 3-5 GHz: low band
  - 6-10 GHz: high band
- Data rates:
  - From 100 Kbps to 27 Mbps
  - 1 Mbps at 2.4 GHz

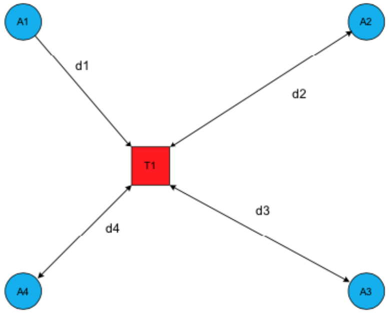
Channel	Center frequency (MHz)	Bandwidth (MHz)
0	499.2	499.2
1	3494.4	499.2
2	3993.6	499.2
3	4492.8	499.2
4	3993.6	1331.2
5	6489.6	499.2
6	6988.8	499.2
7	6489.6	1081.6
8	7488.0	499.2
9	7987.2	499.2
10	8486.4	499.2
11	7987.2	499.2
12	8985.6	499.2
13	9484.8	499.2
14	9984.0	499.2
15	9484.8	1355

- It enables improved localization measures using a physical band with Impulse Radio Ultra Wide Band (IR-UWB)
  - 500 MHz channels will provide accuracy of ~ 2 cm

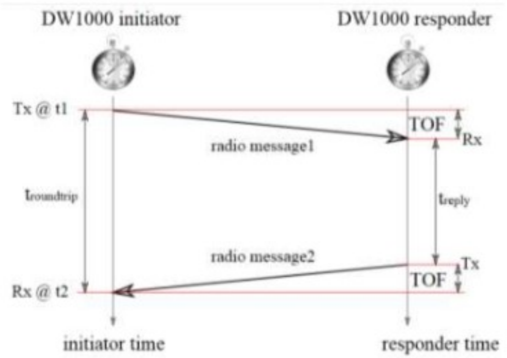
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Ranging

- Real Time Location Systems (RTLS)
  - Anchors and tags



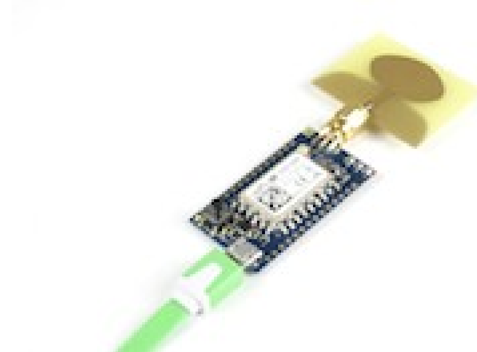
- Two Way Ranging (TWR)
  - B tells A Treply
  - Sources of error:
    - Clock drifts
    - 1cm error → $3,3 * 10^{-11}$s error



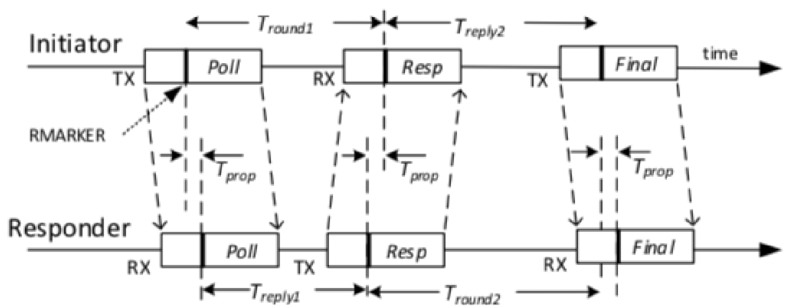
$$TOF = \frac{t_2 - t_1 - t_{reply}}{2}$$

UPC - UNQ

Ranging



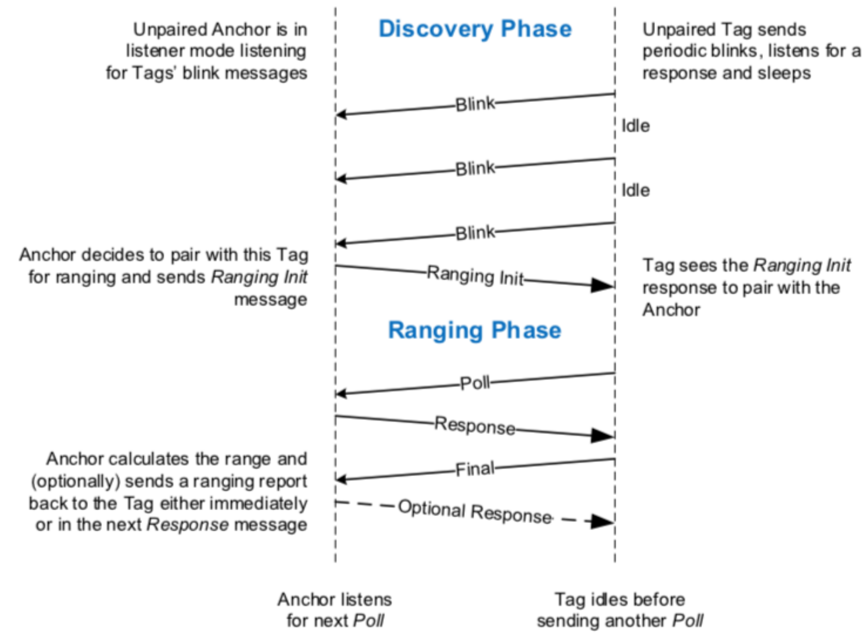
- Decawave + Radino
  - Commercial product
  - Improvement: Asymmetric TWR



The *Final* message communicates the initiator's T_{round} and T_{reply} times to the responder, which calculates the range to the initiator as follows:

$$T_{prop} = \frac{T_{round1} \times T_{round2} - T_{reply1} \times T_{reply2}}{T_{round1} + T_{round2} + T_{reply1} + T_{reply2}}$$

Figure 2: Asymmetric TWR TOF formula

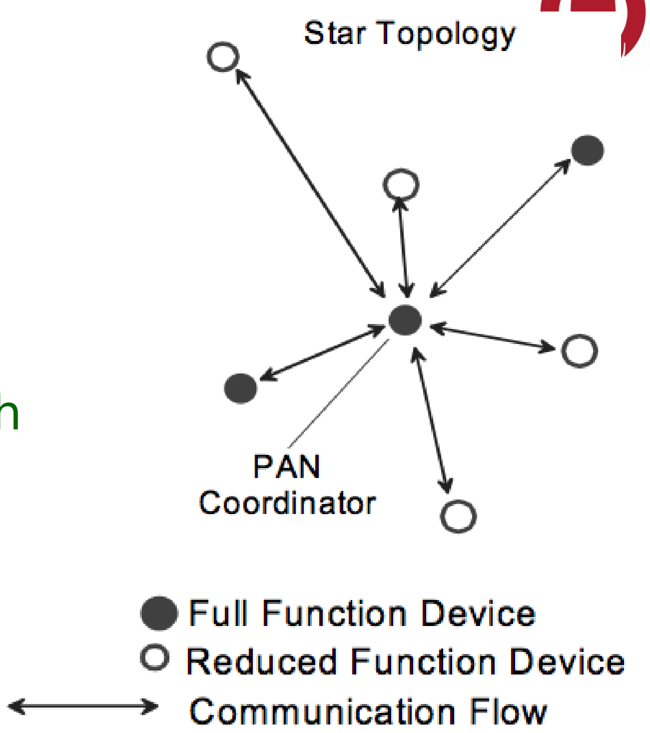


MAC Layer

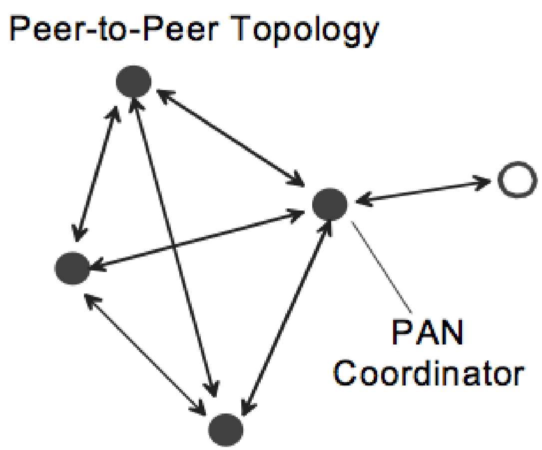
- Maximum Physical Service Data Unit = 127 bytes
- Device types:
  - Full Function Device: FFD
    - It is capable to accept any role in the network
  - Reduced Function Device: RFD
    - It has limited capabilities:
      - It is able to communicate only with FDD devices
    - Intended for very simple applications:
      - Ex: turning on/off a switch
    - Less processing power and memory size than FFD and cheaper!

Network topologies

- Star topology
  - All devices must communicate through PAN Coordinator (FFD)
  - Usually it is the initiation or the termination point for communications
  - PAN coord. uses to be mains powered
  - Home automation, personal computer peripherals, toys and games, health care

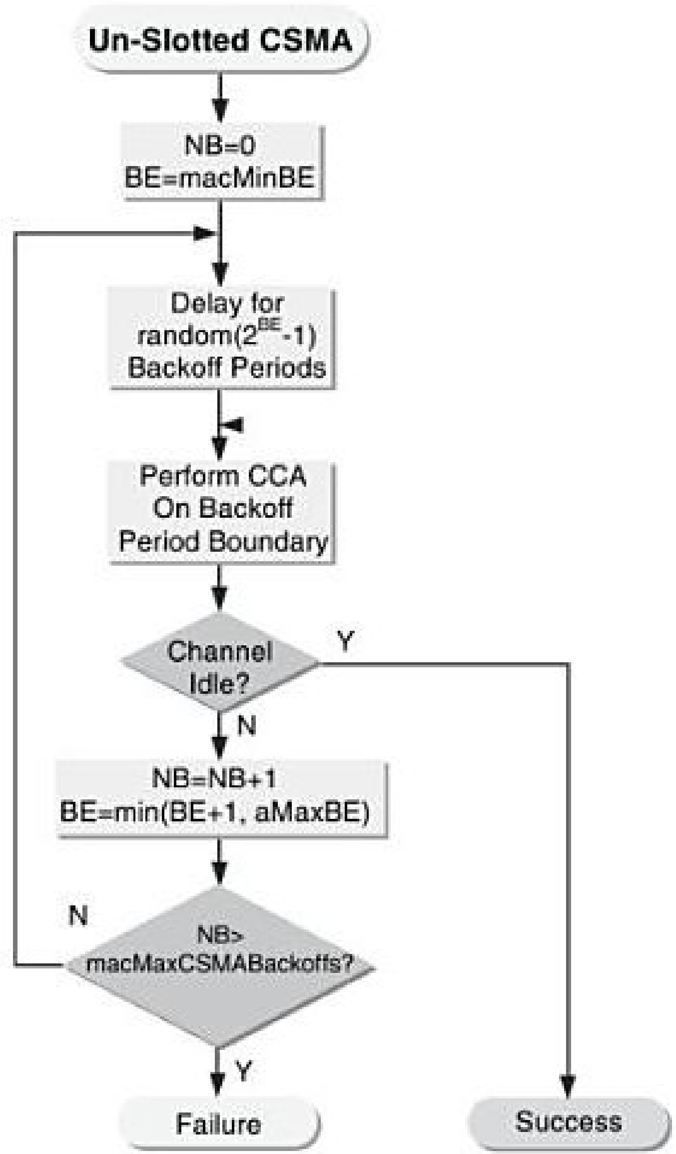


- Peer-to-peer topology
  - Any device may communicate with any other in range
  - It allows more complex network formations
  - Industrial control applications, wireless sensor networks, intelligent agriculture



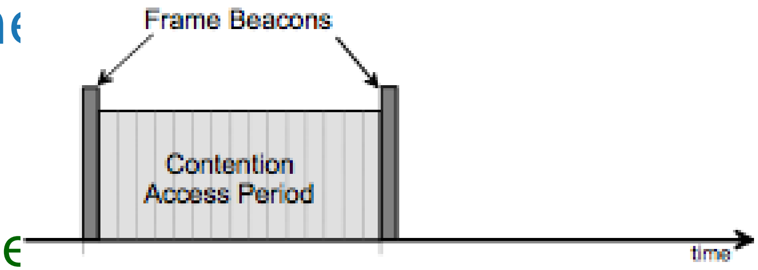
Unslotted CSMA/CA

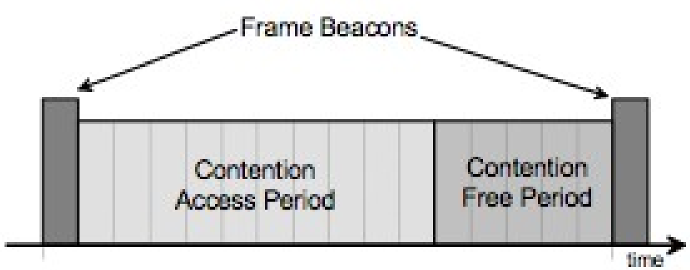
- Similar to 802.11 but non-persistent:
  - Devices wishing to transmit do not listen the medium when performing backoff
    - Saves energy
- Parameters
  - NB: Number of backoffs:
    - To give up Tx attempt
  - BE: Backoff Exponent (min=3)
    - To increase CW
  - Backoff period unit = 20 symbols

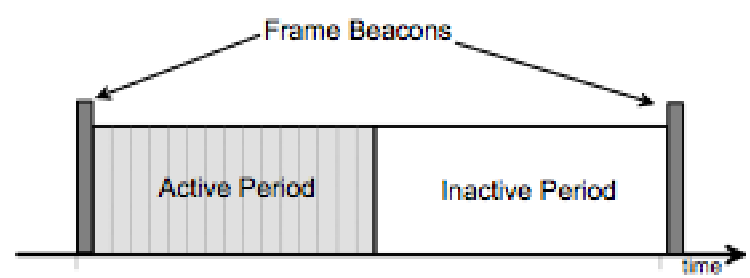


IEEE 802.15.4: Slotted CSMA/CA

- PAN coordinator controls medium access and transmits beacons
- Two beacons define a superframe
- Combination of:
  - Active period
  - Inactive period: Low-power mode
  - CAP: random access similar access method than non slotted
  - CFP: scheduled access (optional)
    - Nodes request bandwidth to coordinator during CAP period

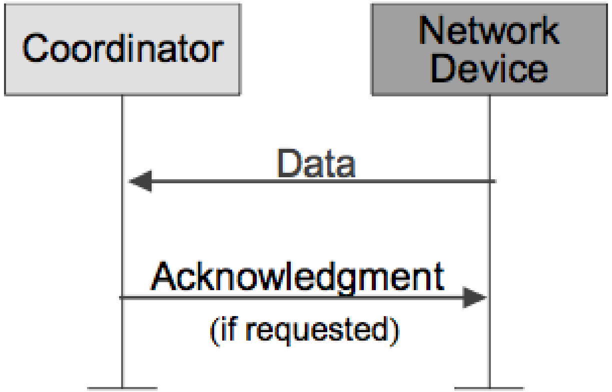






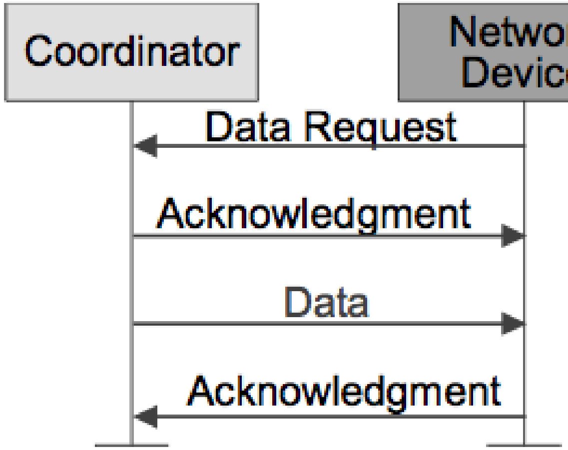
Data transfer to a coordinator: Uplink communication

- A device can initiate the transmission as soon as it is required by the upper layer
- Data + ACK must occur within the active portion of the same superframe



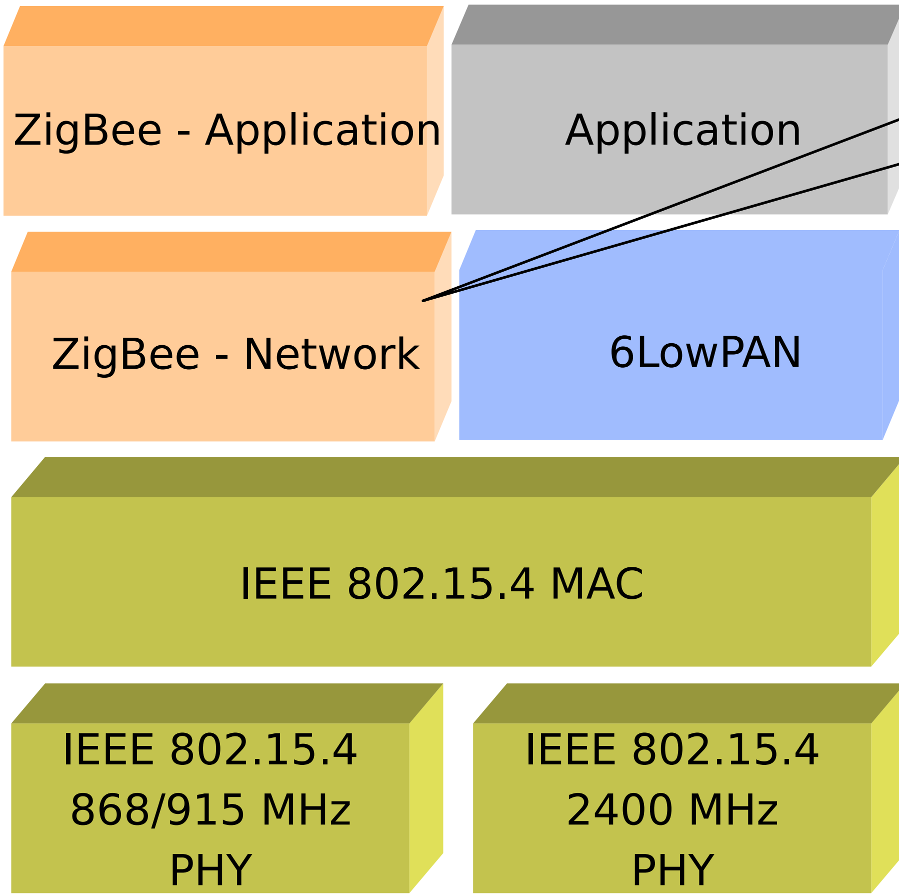
Data transfer from a coordinator: Downlink communication

- More complicate, devices may be sleeping



Upper Layer protocols for IoT

WSN protocol architectures



Zigbee IP and 920IP

http://www.zigbee.org/zigbee-for-developers/network-specifications/zigbeeip/

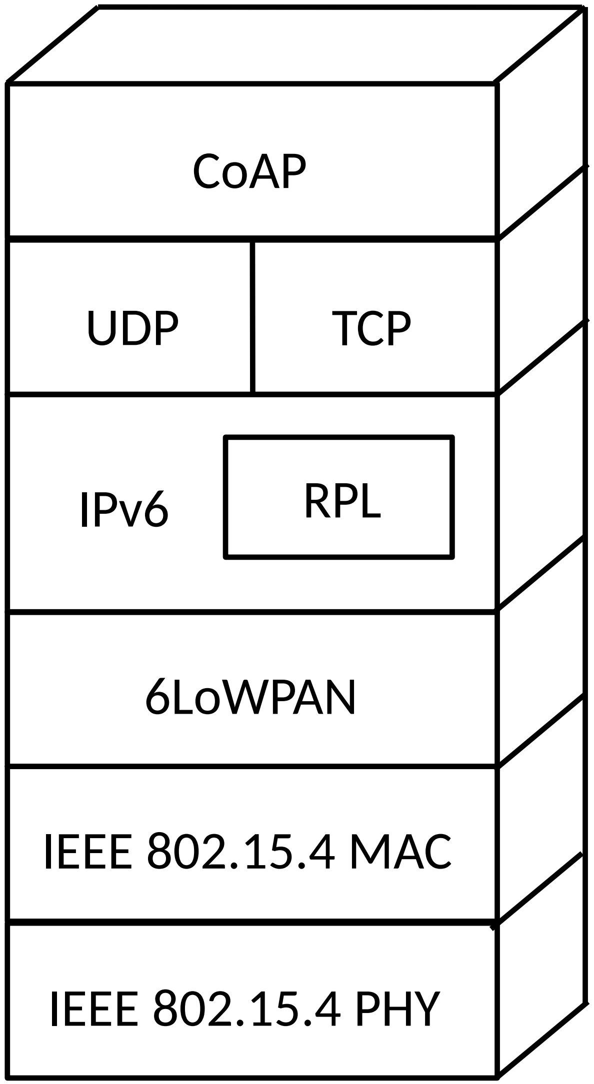
- Routing
- Address resolution
- Packet fragmentation
- Profiles

- Channel acquirement
- Access control
- MAC addressing
- Error control

- Packet transmission
- Packet reception
- Battery management

IETF Vision

- 6LoWPAN
  - IPv6 over Low power Wireless Personal Area Networks (6LoWPAN)
  - Adaptation layer between to (efficiently) support IPv6 over IEEE 802.15.4
    - Fragmentation
    - Header compression
    - Optimized Neighbour Discovery
  - Currently handled by the 6Lo WG
  - Sometimes, "6LoWPAN" used to denote the whole IETF protocol stack
  - Other IoT-specific protocols in the stack:
    - RPL (RFC 6550): routing
    - CoAP (RFC 7252): application layer

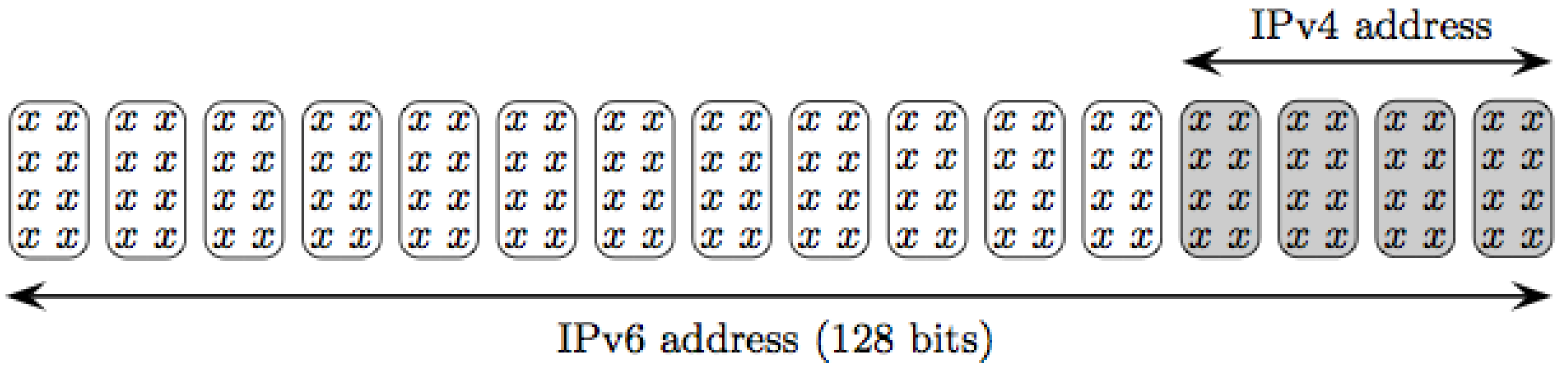


IPv6

- Increments address space
- Simplifies IP header
- Integrates all additional protocols and autoconfiguration in ICMPv6

IPv6 address space

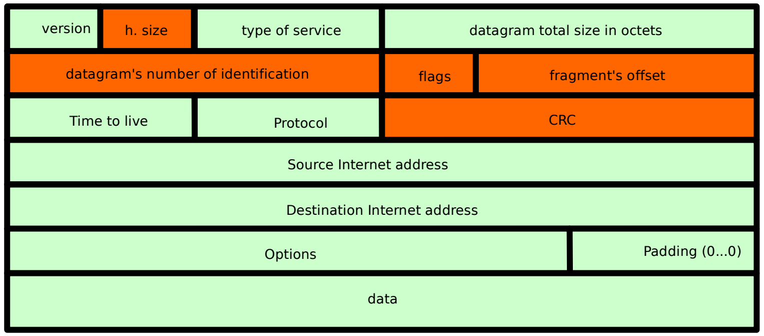
- IP addresses: 128 bits



- 2^{128} possible addresses
- How big is this number?
  - 340,282,366,920,938,463,463,374,607,431,768,211,456 addresses ≈ 3.4 x 10^{38}
  - 6.65 x 10^{23} addresses for every square meter of the Earth's surface

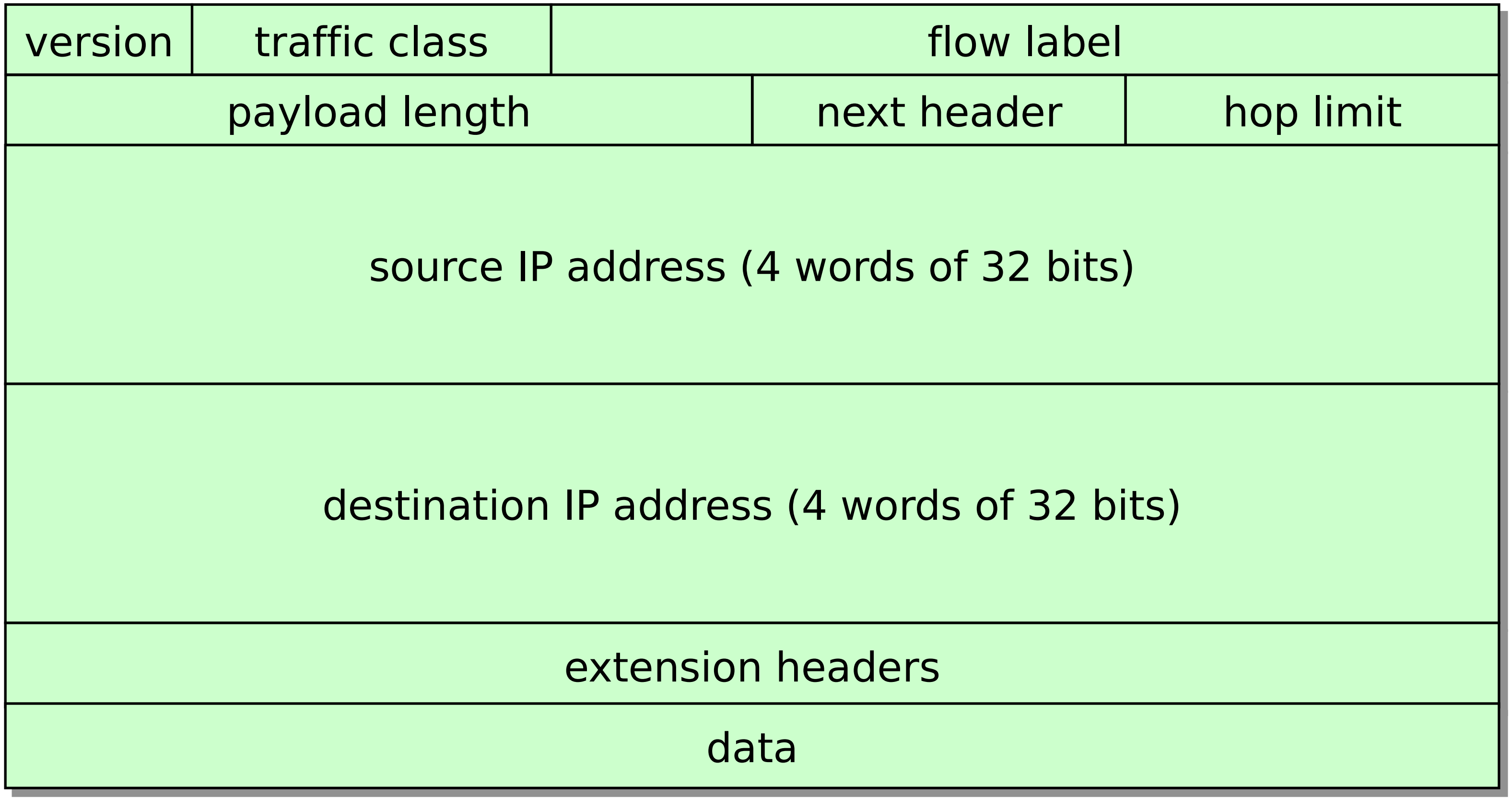
IPv6 address notation

- IPv6 addresses are written in hexadecimal pairs of bytes separated by colons
  - Block: a pair of bytes
  - Nibble: hexadecimal digit (half byte)
- Examples:
  - `2001:0000:0000:0000:020c:f1ff:fefd:d2be`
- To abbreviate it, within each block, leading zeros may be omitted:
  - `2001:0:0:0:20c:f1ff:fefd:d2be`
- Compressed form: in every address at most one sequence of zero-blocks may be written as two consecutive colons:
  - `2001::20c:f1ff:fefd:d2be`



IPv6 Header

- 40 bytes (minimum)



ICMPv6 vs. ICMPv4: change of philosophy

- Internet Control Message Protocol
- The role of ICMP in IPv4 networks:
  - Basically, ICMPv4 is intended to send error and informational messages
- Things have changed with IPv6:
  - ICMPv6 also sends error and informational messages, but also has other roles:
    - Neighbor reachability: substitutes ARP
    - Multicast membership: substitutes: IGMP
    - Address autoconfiguration: New!
    - Mobile IP

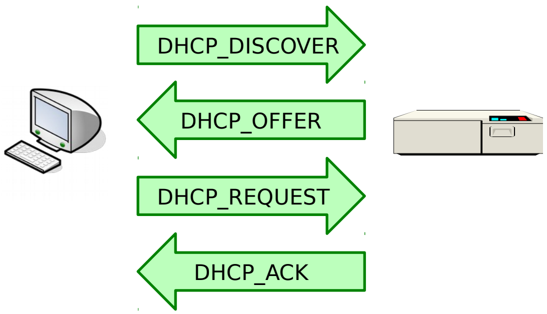
Type of ICMPv6 messages

- Type
  - 1 E Destination unreachable
  - 2 E Packet too big
  - 3 E Time exceeded
  - 4 E Parameter problem
  - 128 R/R Echo request
  - 129 R/R Echo reply
  - 130 M Multicast Listener Query
  - 131 M Multicast Listener Report
  - 132 M Multicast Listener Done (leave group)
  - 133 D Router solicitation
  - 134 D Router advertisement
  - 135 D Neighbour solicitation
  - 136 D Neighbour advertisement
  - 137 D Redirection
  - 143 M Version 2 Multicast Listener Report
  - 144 Mob Home Agent Address Discovery Request Message
  - 145 Mob Home Agent Address Discovery Reply Message
  - 146 Mob Mobile Prefix Solicitation
  - 147 Mob Mobile Prefix Advertisement
  - others

E: error
R/R: Request/Reply
M: Multicast
D: Neighbour discovery
Mob: IP mobile

Interface configuration in IPv4

- Network interface configuration requires:
  - IP address / Netmask
  - Default router
  - DNS server
- These parameters can be set:
  - Manually by the user
  - Automatically by a DHCP server

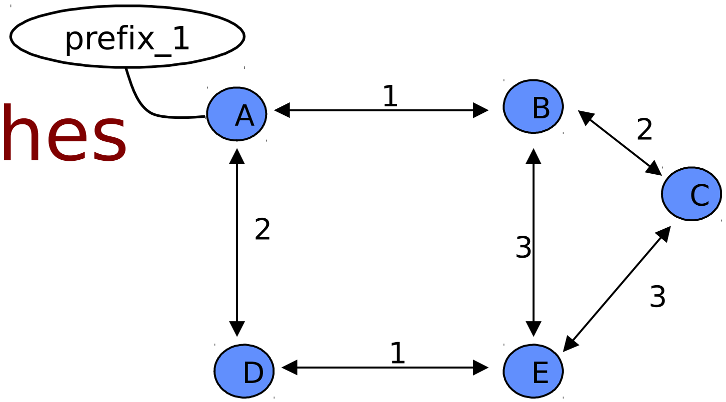


- DHCP (Dynamic Host Configuration Protocol)
  - Address assignation from a block of addresses
  - DHCP allows a client to specify the requested parameters
  - Automatic or manual assignation of the addresses

Interface configuration in IPv6

- Possibilities to configure network interfaces:
  - Always a minimum autoconfiguration: New!!
  - Manually
  - Using ICMP messages from routers: New!!
  - With a DHCP server
- Procedure for Autoconfiguration:
  - Link local address is always active
    - It enables to connect with any computer of the same link
    - Interface ID derived from MAC address or chosen randomly
  - Router transmits Router Advertisement (daemon radvd)
    - It sends network parameters and says what to do:
      - To use a DHCP server
      - To use a specific global prefix, to which devices have to add the Interface ID

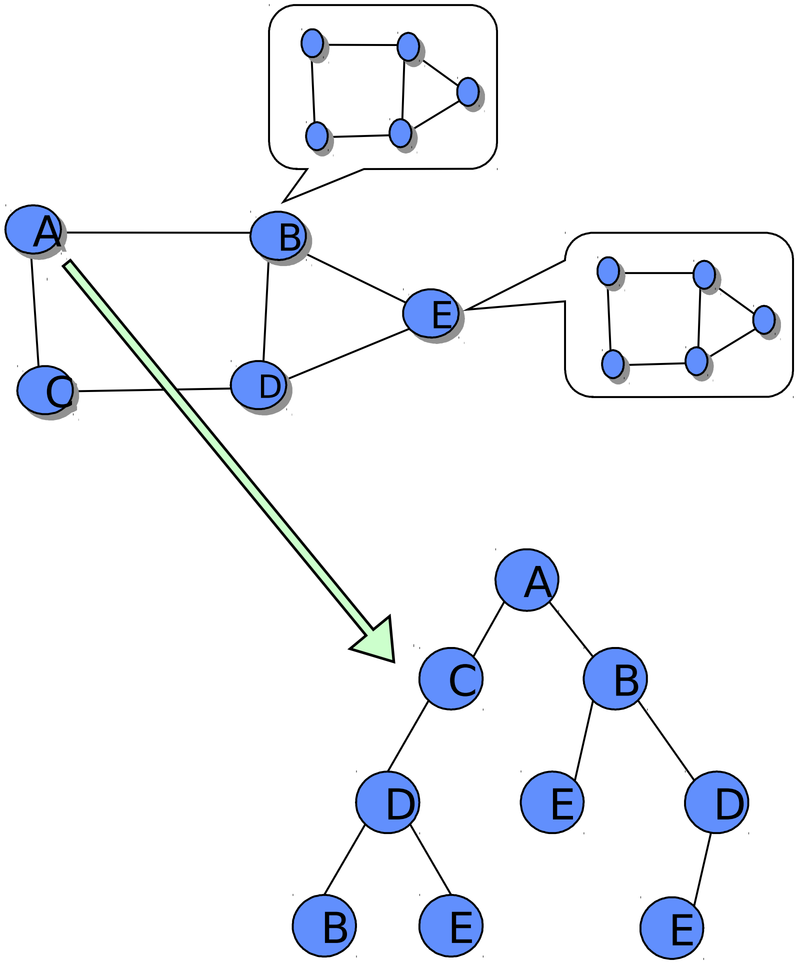
IP Routing approaches



- Distance vector
  - Each link has a cost
  - Each node sends distance vectors (prefix, cost) to its neighbours
  - When receiving a vector, routing table information is updated if:
    - There was no information about this node
    - Using the same link, the cost is different
    - Using another link, the cost is smaller
    - Each time that the table is updated, a new vector is sent
  - Routers only know one path to each destination
  - RIP uses this approach

IP Routing approaches

- Link state
  - Routers interchange information about network topology
  - All have the same information
  - They calculate the shortest path tree
  - Routers know alternative paths to same destination
  - More complex than distance vector
  - OSPF uses this approach



Routing in Mobile Adhoc Networks

- Many protocols
  - Protocols adapted from fixed networks
  - New protocols for ad hoc
  - There is no one that behaves well in all environments
- Proactive protocols
  - Always have an updated routing table
  - Low latency (delay)
- Reactive protocols
  - Routing tables are updated only when they are active
  - Less management but more latency than proactive
- Hybrid protocols

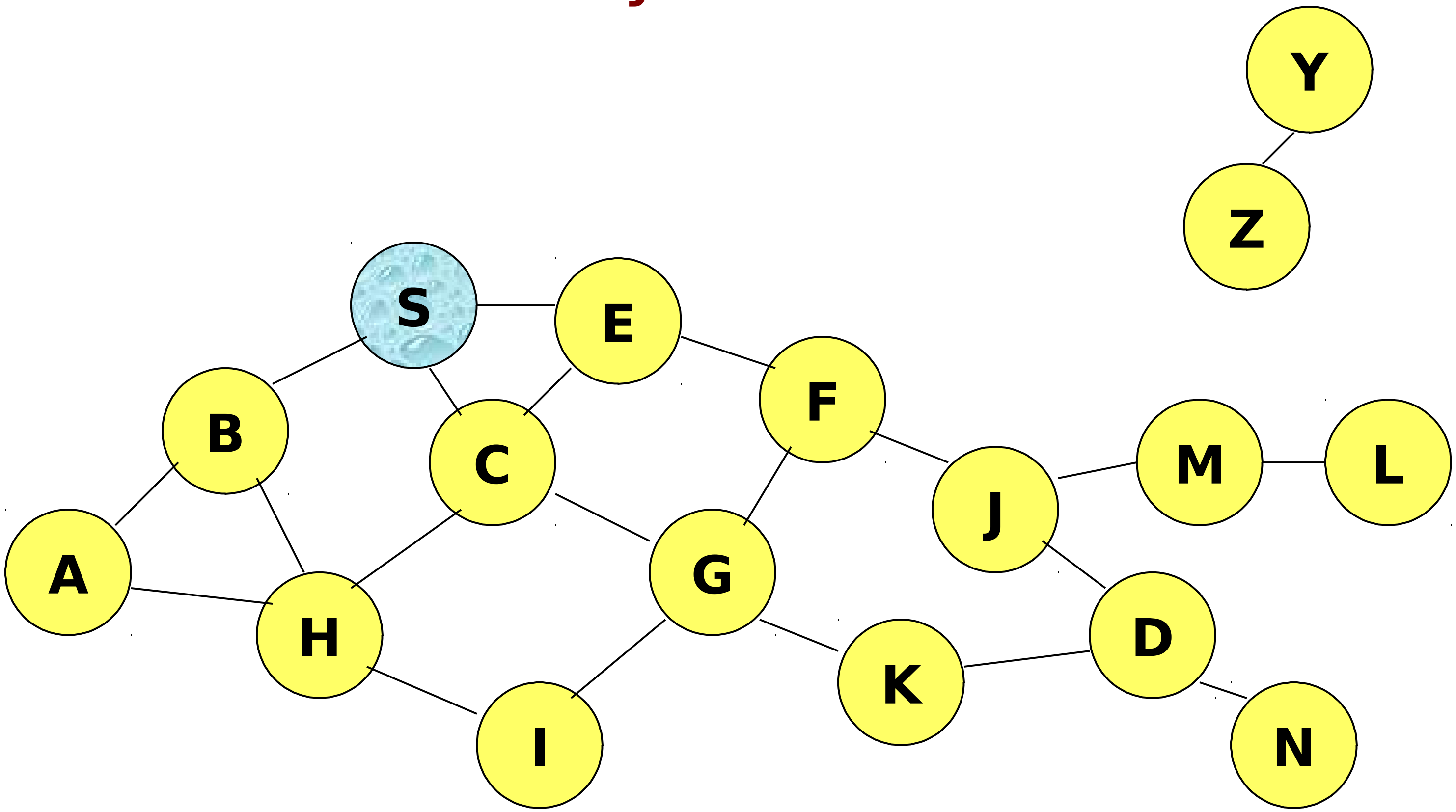
Routing protocols

- Proactive
  - DSDV: Destination Sequenced Distance Vector
  - WRP: Wireless Routing Protocol
  - CGSR: Cluster Switch Gateway Routing
- Reactive
  - ABR: Associability Based Routing
  - DSR: Dynamic Source Routing
  - TORA: Temporally Ordered Routing Algorithm
  - AODV: Ad Hoc On-Demand Distance Vector Routing
  - DYMO: Dynamic MANET On-demand – DYMO-low
  - RDMAR: Relative Distance Microdiversity Routing
  - SSR: Signal Stability Routing
  - LAR: Location-Aided Routing
  - PAR: Power-Aware Routing
- Hybrid
  - ZRP: Zone Routing Protocol

Dynamic Source Routing - DSR

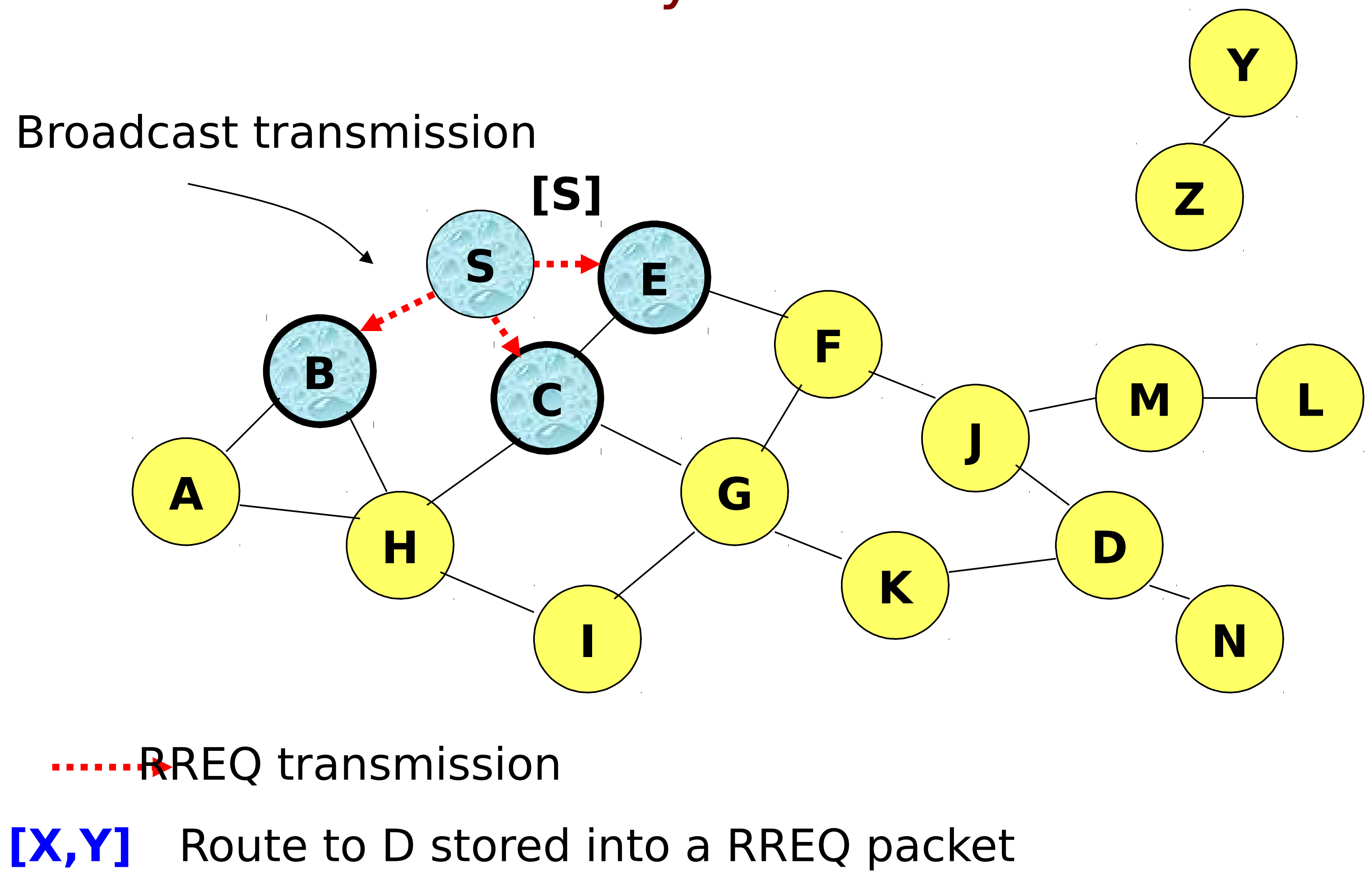
- Reactive protocol
- Source Routing
- Mobile nodes have routes in cache memory
- How it works:
  - When node S has to send a packet to node D, but it doesn’t know the route, it initiates a Route Discovery procedure (RREQ)
  - RREQ packets propagate until destination or another node that knows the route to D
  - After that, node S stores the route and sends packets

DSR - Route Discovery

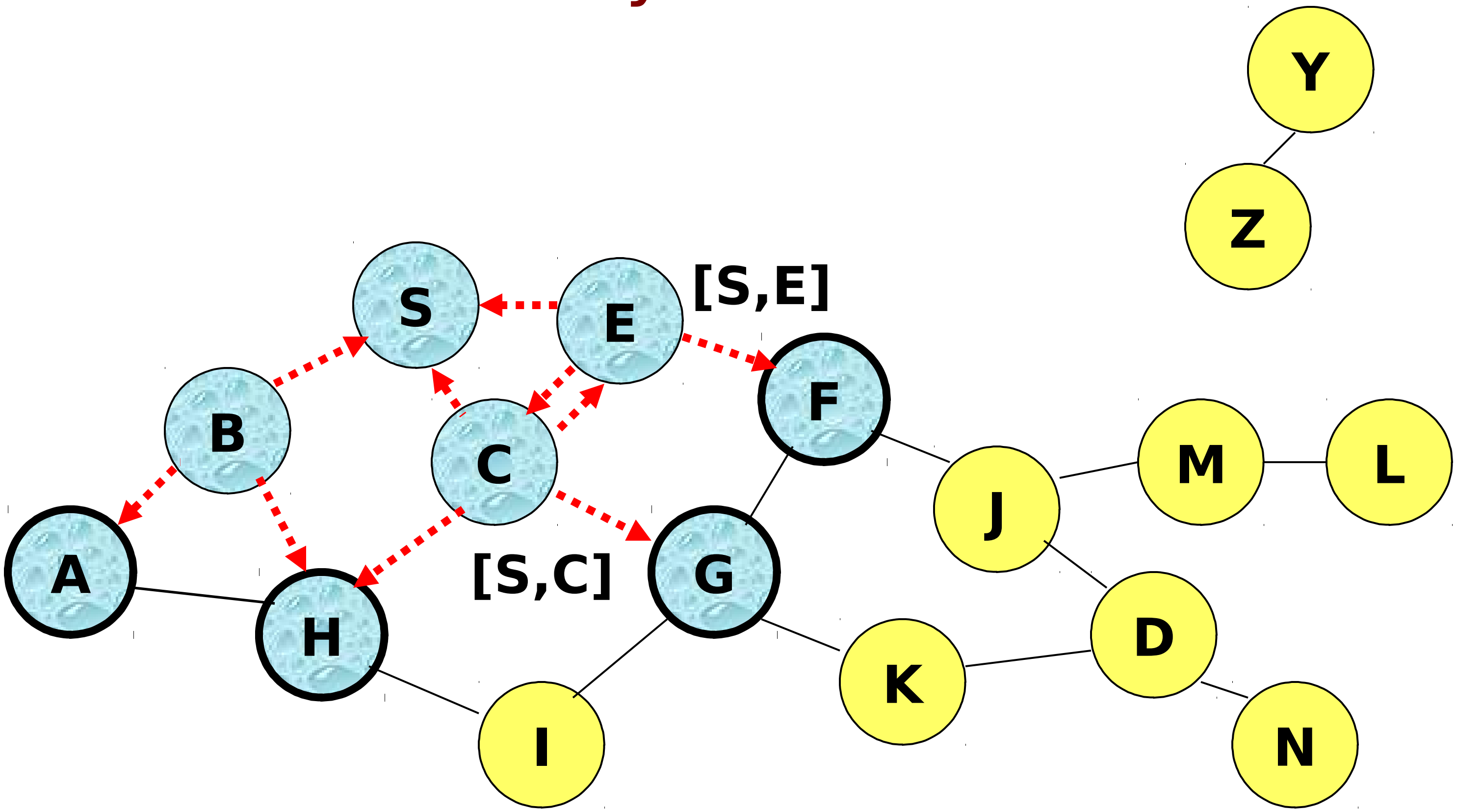


Node that receives a RREQ to D from S

DSR - Route Discovery

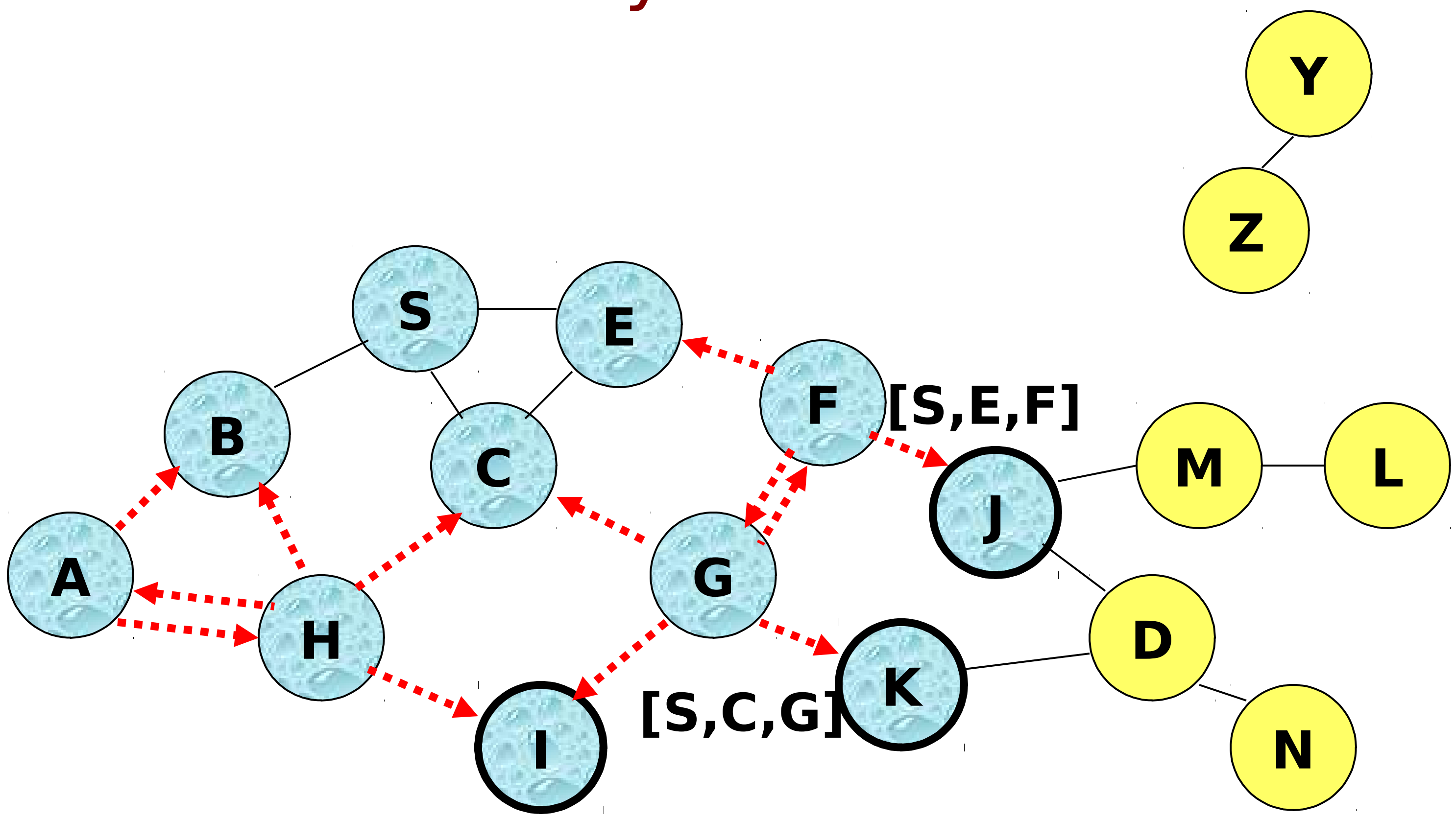


DSR - Route Discovery



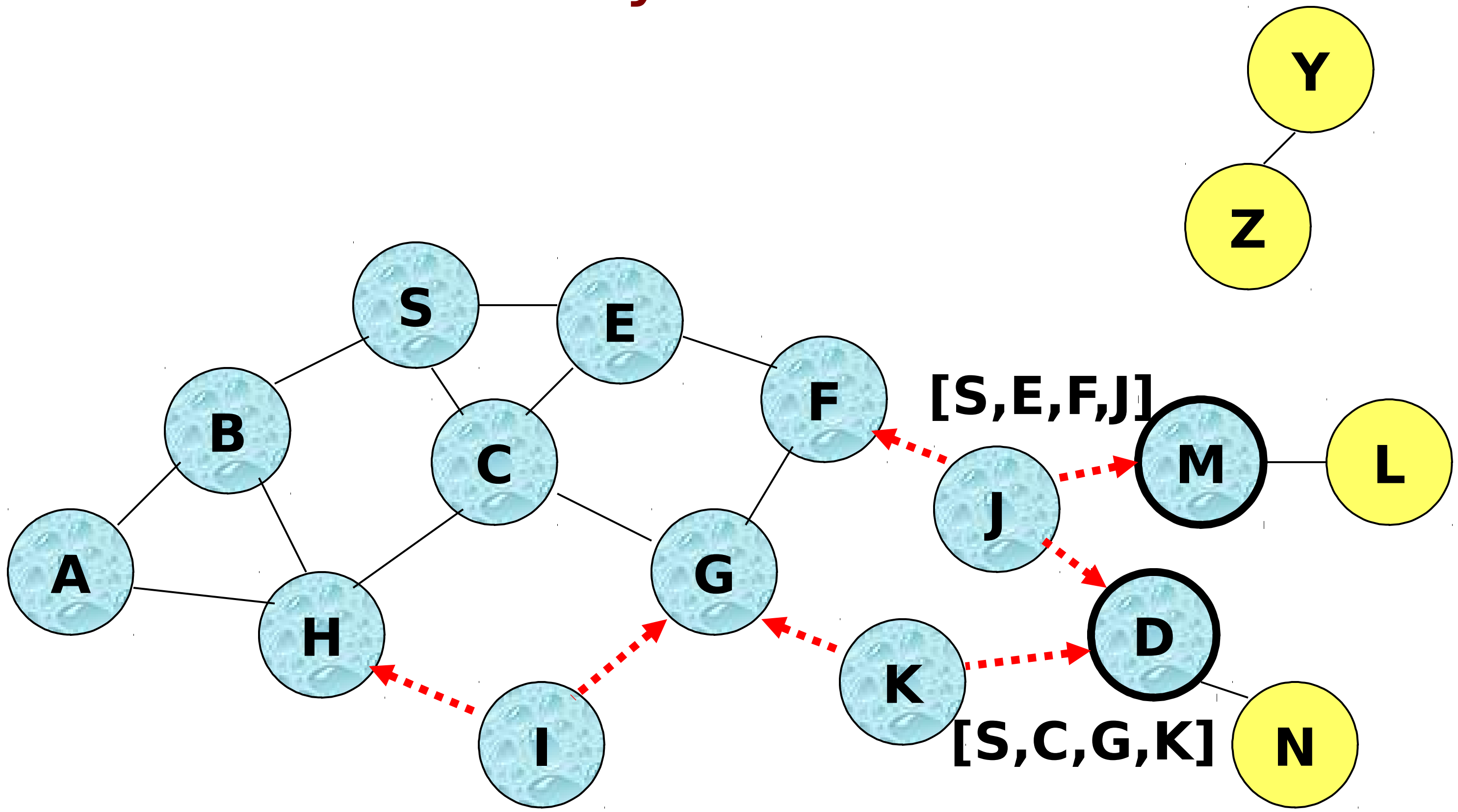
H gets two RREQ packets. Possible collision.

DSR - Route Discovery



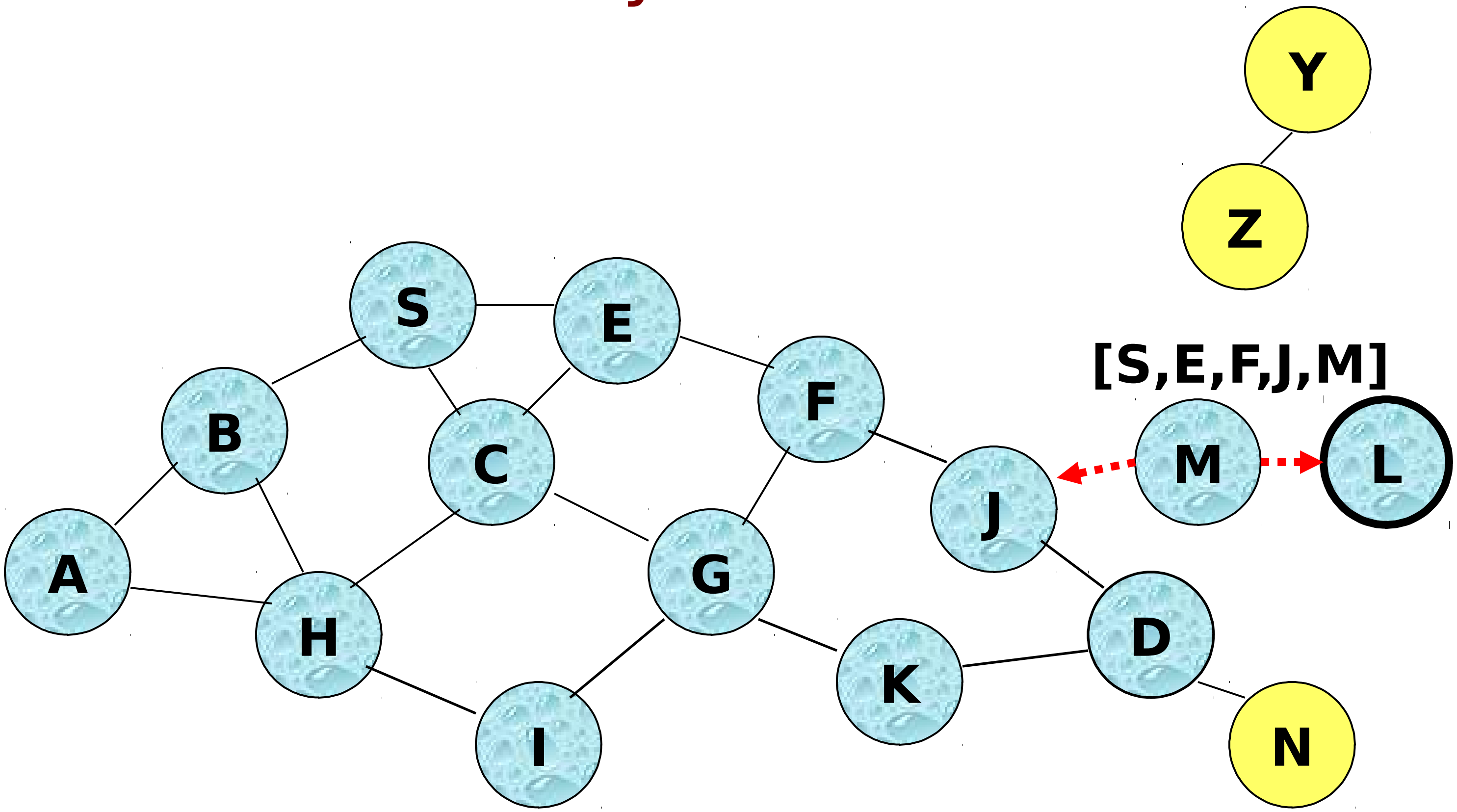
Node C receives a RREQ from G and H, but doesn't forward them because it has already done once

DSR - Route Discovery



J and K nodes forward RREQ to node D

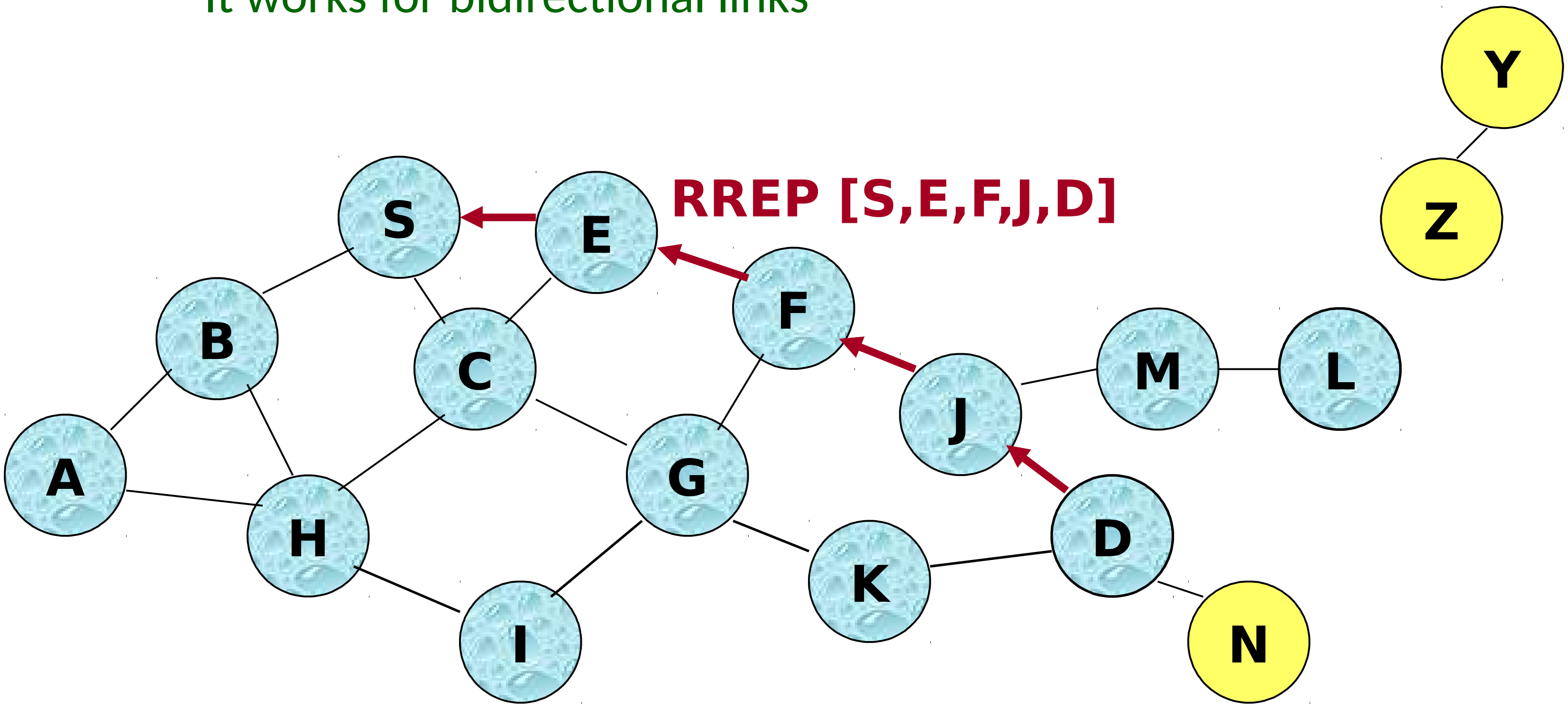
DSR - Route Discovery



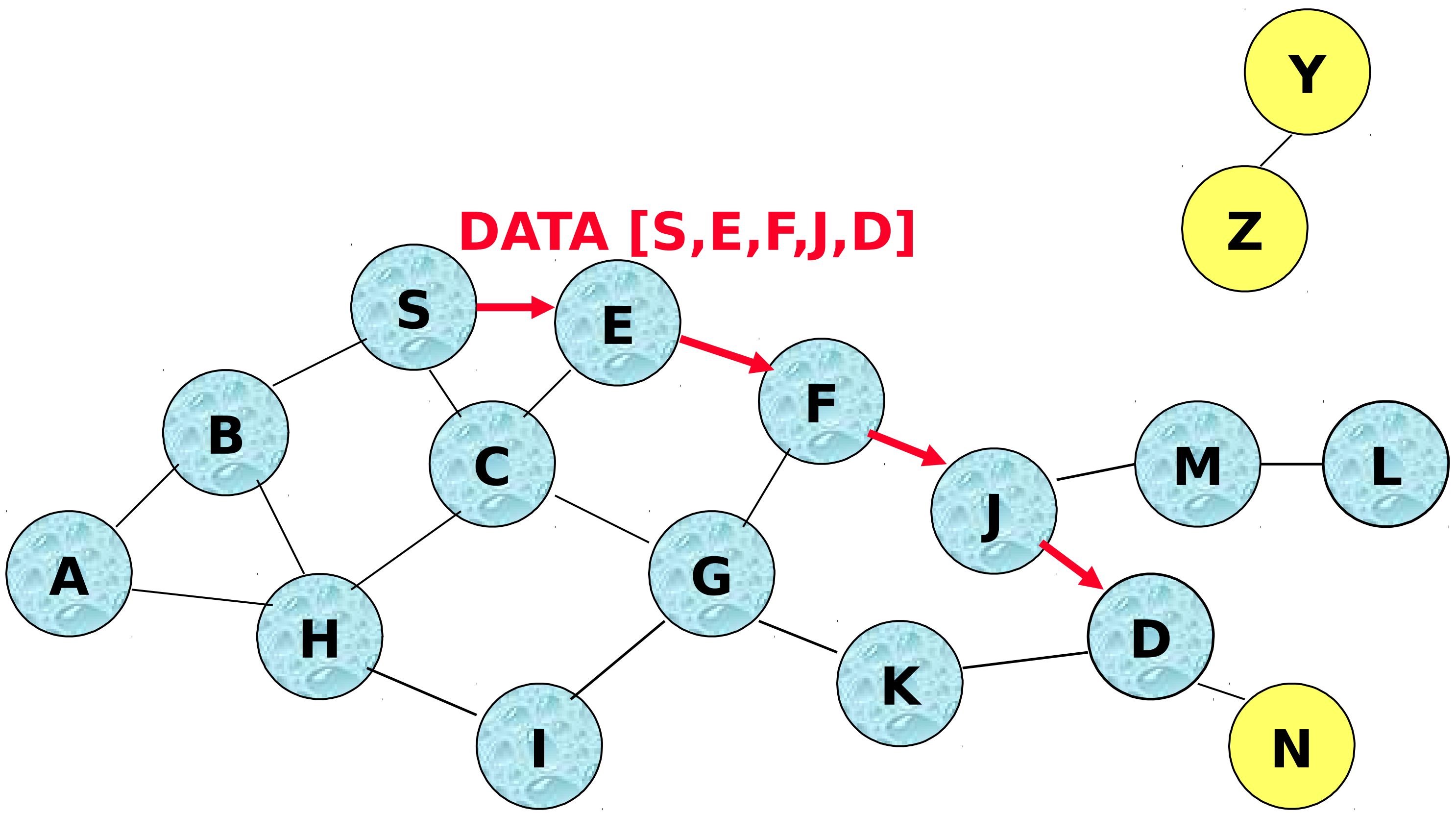
Node D doesn't forward RREQ because it is the destination

DSR - Route Reply

- When D gets the first RREQ, it replies with a RREP
  - It follows the route stored in RREQ from S to D backwards
  - It works for bidirectional links



DSR – Data transmission



AODV

- Ad Hoc On-Demand Distance Vector Routing
  - Charles Perkins 1999
- Reactive routing
- Tries to improve DSR:
  - It maintains routing tables in order that packets should not content destination route
  - Routes have identification number to detect old ones
  - Routes have life time and expire
  - Each node has a list of neighbors that use him to relay data
  - When a route expires it is notified to neighbors (RERR)
  - It uses Hello packets to detect neighbor connectivity
    - When Hello packets do not arrive: connectivity failure

Application level

CoRE (Constrained RESTful Environments)

CoAP

HTTP not suitable for IoT

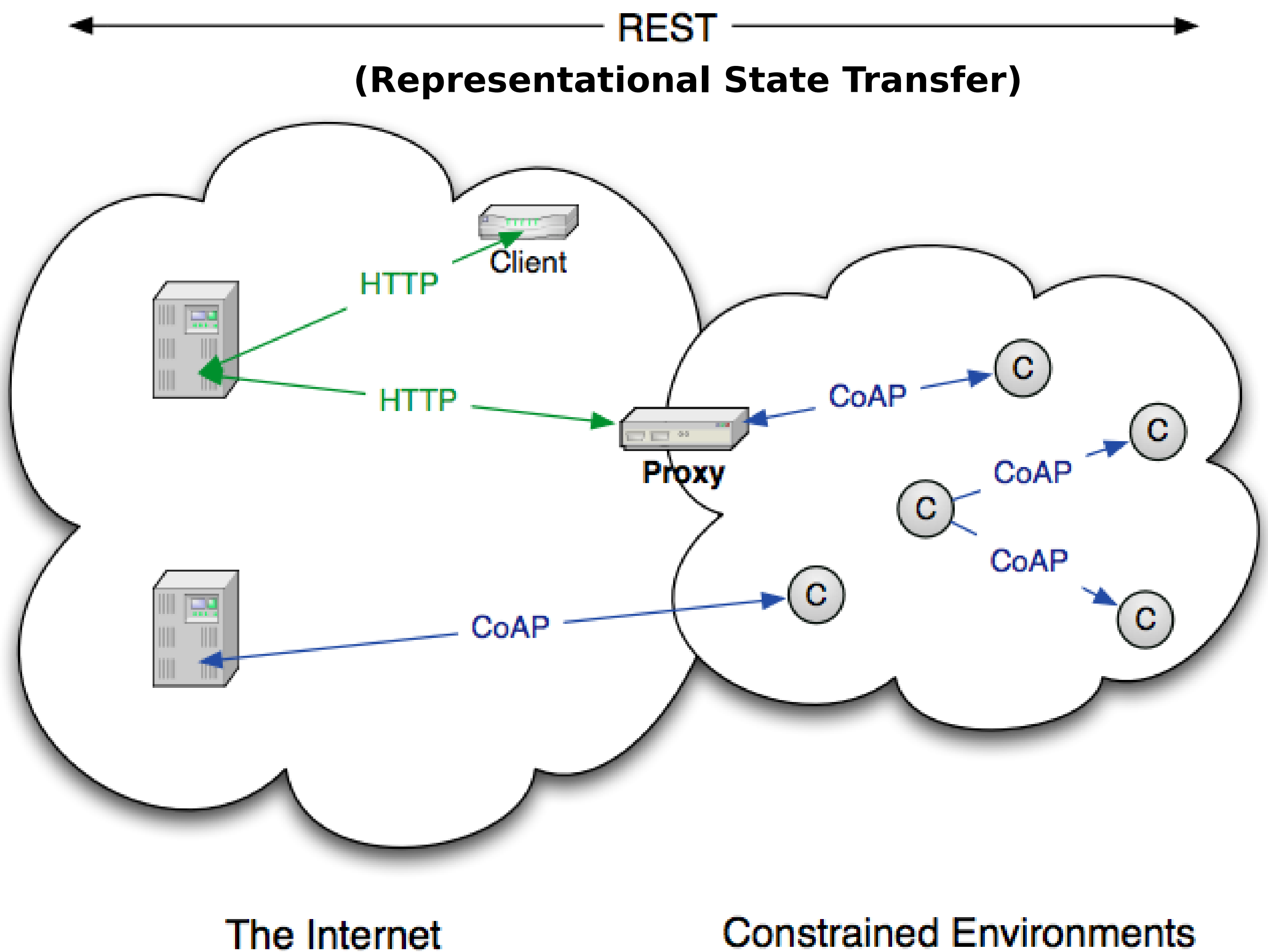
- HTTP is a REST protocol but, for IoT is:
  - Too complex: parsing (text to variable conversion)
  - Implies the usage of TCP
  - Messages with too many bytes
  - No support for sleeping nodes

- So new solutions were needed
  - IETF created CoRE (Constrained RESTful Environments (CoRE) Working Group
  - Objective: to provide new solutions to the existing application protocols not suited for constrained networks based on IP

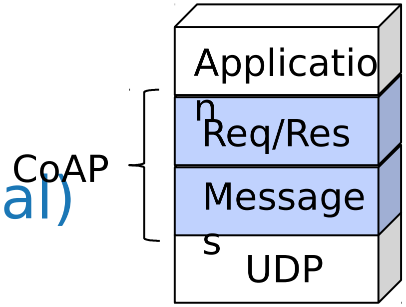
CoAP (Constrained Application Protocol)

- Is:
  - A RESTful protocol
  - Both synchronous and asynchronous are possible
  - For constrained devices and networks
  - Specialized for M2M (Machine-to-Machine) applications
  - Easy to proxy to/from HTTP
- Is not:
  - A replacement for HTTP
  - An HTTP compression
  - Separated from the web

CoAP usage and architecture

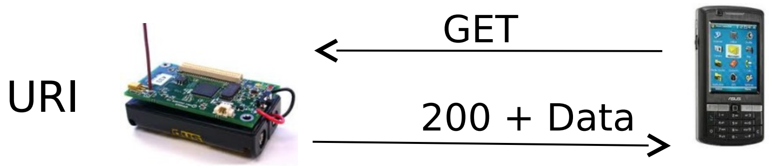


CoAP



- Client/Server Model (UDP, TCP optional)
- Double layer approach
  - Requests (client) and responses (server) model
  - Messages
- Interaction model of CoAP similar to model of HTTP
  - Clients send requests using a Method code of a resource (identified by a URI) on a server
    - Example of URI: coap://example.com:5454/sensors.xml
  - A response is then sent with a Response Code and resource representation, if appropriate

METHODS in CoAP



- Basic RESTful methods
  - GET, POST, PUT, DELETE
  - Easily mapped to HTTP

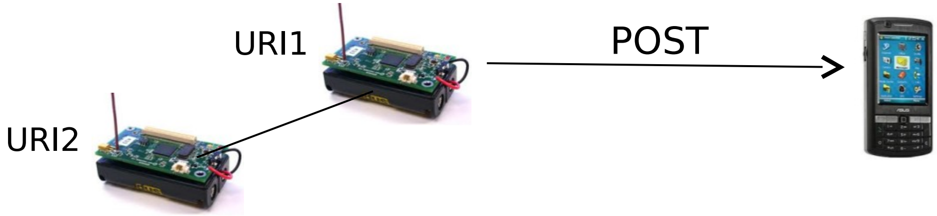
- GET retrieve resources from the WSN nodes
  - Resource identified by the Uniform Resource Identifier (URI)
  - Upon success, a 200 (OK) response should be sent

- PUT to modify/create an existing resource on a sensor node

METHODS in CoAP

- POST to request the server to create / change / delete a resource under the requested URI
  - The response can be: Created / Changed / Deleted

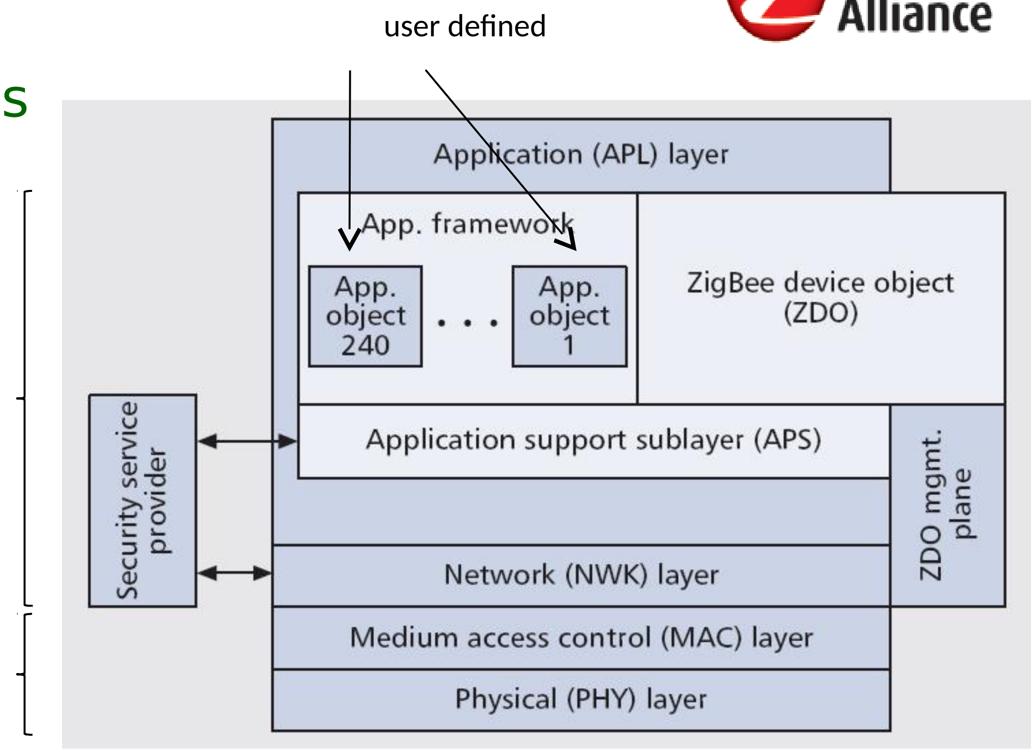
- DELETE to request to delete the specified URI
  - Upon success, a 200 (OK) response should be sent on success



ZigBee

ZigBee Vision

- Protocols architecture over IEEE 802.15.4
- Developed and promoted by ZigBee Alliance
  - First version in 2004
- Generic purpose
  - Application profiles



ZigBee: profiles

- ZigBee Building Automation
- ZigBee Smart Energy
- ZigBee Home Automation
- ZigBee Remote Control
- ZigBee Input Device
- ZigBee Retail Services
- ZigBee Telecom Services
- ZigBee 3D Sync
- ZigBee Health Care

ZigBee Versions

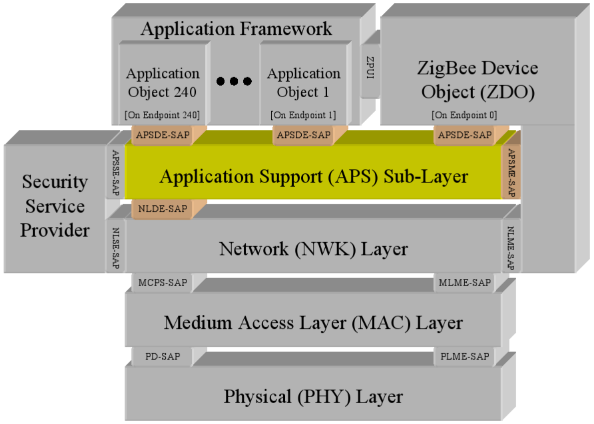
- ZigBee 2004: First version
- ZigBee 2006: Most used nowadays
- ZigBee 2007 also named ZigBee Pro:
  - Optimization of Network Level
  - Data aggregation
  - Some new profiles

UPC - UNQ

ZigBee Network Layer tasks

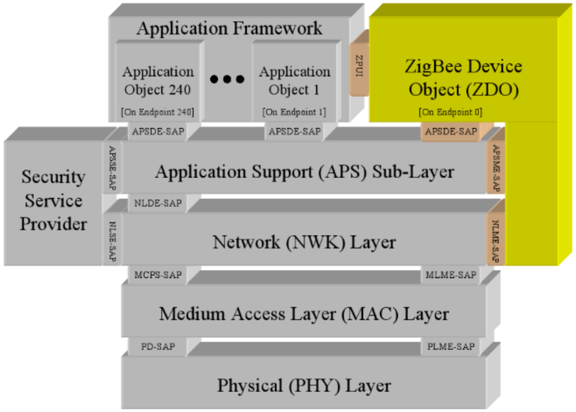
- Network layer:
  - Create a new network
  - Join and leave a network
  - Assign Network addresses to newly associated devices
  - Discover one-hop neighbours
  - Store pertinent neighbour information
  - Discover and maintain routes between devices
  - Route frames to their intended destinations
  - Apply security to frames

ZigBee



- Application:
  - Application Support Sublayer (APS)
    - Maintaining tables for binding (the ability to match two devices together based on their services and needs)
    - Forwarding messages between bound devices
    - Address mapping from 64 bit MAC to 16 bit NWK
    - Fragmentation, reassembly and reliable data transport

ZigBee



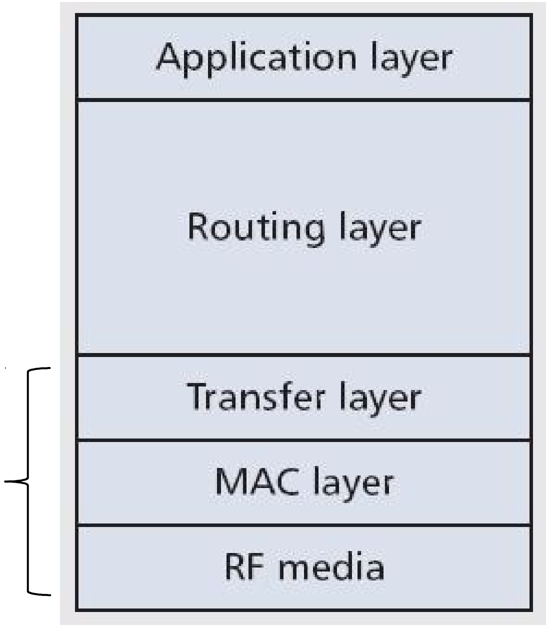
- Application:
  - ZigBee Device Objects (ZDO)
    - Defining the role of the device within the network (device or coordinator)
    - Initiating and/or responding to binding requests
    - Establishing a secure relationship between network devices
    - Discovering devices and determining which application services they provide

Z-Wave

Z-Wave

- Z-Wave radio technology
  - Originally, proprietary
    - Developed by ZenSys (2003)
      - Subsequently acquired first by Sigma Designs, later by Silicon Labs (2018)
      - Z-Wave Alliance: 700 companies
    - Protocol stack for home automation
      - 100 million devices sold (claimed)
      - Spec currently open to the public
        - Had been closed for many years
  - Supports mesh topology

ITU-T G.9959



Z-Wave

- Physical layer (ITU-T G.9959)
  - Wireless, sub-1 GHz bands: 868 and 915 MHz
  - R1 (9.6 kbps), R2 (40 kbps), R3 (100 kbps)
- Device types
  - Controllers: poll or send commands to the slaves
  - Slaves: reply to the controllers
    - Suitable for sensors and actuators
- Routing
  - Controllers have the full network map
  - Controllers use source routing
    - Up to 4 hops, maximum
- Application layer
  - Commands

Z-Wave

- Example products

Smart alarm
(presence sensor +
remote on/off)

Smart plug (on/off +
energy consumption
monitoring)

Water shut off valve

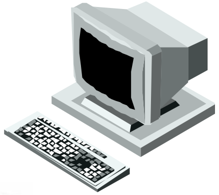
Garage door
controller

Smart window controller

Bluetooth Low Energy

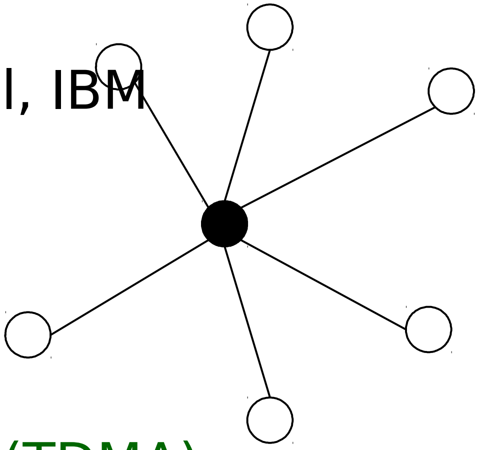
Bluetooth

- Quintessential Wireless Personal Area Network (WPAN) technology
  - Coverage < WLAN
    - Typically, ~10 m (or a few 10s of metres)
  - Main goal: communication among the devices in a person's environment
    - PC, phones, cameras, peripherals (keyboard, mouse, etc.), headsets, etc.
    - "Removing the cables"
  - Also for Internet access
    - Not so common
  - Other competing technologies
    - Infrared (today mainly limited to remote control applications


Bluetooth

- Created by Ericsson (1994)
- Specified by the Bluetooth Special Interest Group
  - Bluetooth SIG
  - Established in 1998
    - Initially: Ericsson, Nokia, Toshiba, Intel, IBM
- Operates in the 2.4 GHz ISM band
- It defines a network called piconet
  - Star topology
  - One master and up to seven slaves
  - Communication takes place in timeslots (TDMA)
  - The master controls medium access and determines resource assignment
- It is possible to create larger networks
  - Scatternets



Bluetooth

- Bluetooth 1.1
  - Ratified as IEEE 802.15.1-2002
- Bluetooth 1.2
  - Ratified as IEEE 802.15.1-2005
  - Up to 721 kbps
- Bluetooth 2.0 + Enhanced Data Rate (EDR) (2004)
  - EDR is optional, up to 2.1 Mbps
- Bluetooth 3.0 + High Speed (HS) (2009)
  - HS is optional, up to 24 Mbit/s
- Bluetooth 4.0 (2010): Bluetooth Low Energy (BLE)
  - BLE stack is not interoperable with classic Bluetooth stack
  - Bit rate is 1 Mbit/s
  - Range of (typically) various tens of meters

Bluetooth 4.1, 4.2

- Bluetooth 4.1 (2013)
  - Coexistence with other systems (802.11, 4G, …) by coordinating interfaces' activities within a device
  - Slave allowed to be connected to more than one master
    - "IoT": i.e. devices connected to a phone can now talk directly
- Bluetooth 4.2 (2014)
  - Data channel payload size increase up to 251 bytes
    - Throughput and capacity increase
  - Integrates support for IPv6
- Bluetooth 5.0 (2016)
  - Greater bit rate: 2 Mbps
  - "LE coded": Greater range (x4)
    - Data rate decrease (125 kbps and 500 kbps)
  - Beacon size Increased from 31 bytes to 255 bytes
    - Allows for URLs, telemetry data, etc.

UPC - UNQ

BLE beacons

- Advertising
  - Broadcasting ID and/or sensed data
- Applications
  - Sensed data
  - Localization
  - Geomarketing
  - Tracking
- Examples
  - Volkswagen connect
  - Samsonite Track & Go

Source: Aislelabs

Bluetooth Mesh

- Published in July 2017
- Need for extended topology
  - Beyond star topology

Image source: SlashGear

Low Power Wide Area Networks (LPWAN):

Sigfox

LoRa

Cellular IoT

LoRa

- LoRa (Long Range) is organized around LoRa Alliance industry consortium launched at MWC'15 with the following Sponsor Members:

- The LoRa Alliance has defined the LoRaWAN comprising MAC and network stack around the LoRa modulation

LoRa

- Low Power – Long Range
- Frequency bands: 433, 868 and 915 MHz
- Channels of 125 kHz, 250 kHz or 500 kHz using Chirp Spread Spectrum (CSS)
- Range:
  - Up to 15 Km in suburban areas
  - Up to 5 Km in urban areas

- LoRa modulation is copyrighted by Semtech
  - Other chip manufacturers pay royalties to Semtech

SEMTECH HOPERF MICROCHIP

LoRa Channels and Spreading Factors (SFs)

Sub-band	Freq. Range (MHz)	Conditions (Pwr/DC)
g1	868.0 – 868.6	14 dBm @ 1%
g2	868.7 – 869.2	14 dBm @ 0.1%
g3	869.4 – 869.65	27 dBm @ 10%
g4	869.7 - 870	14 dBm @ 1%

10 channels of 125 KHz

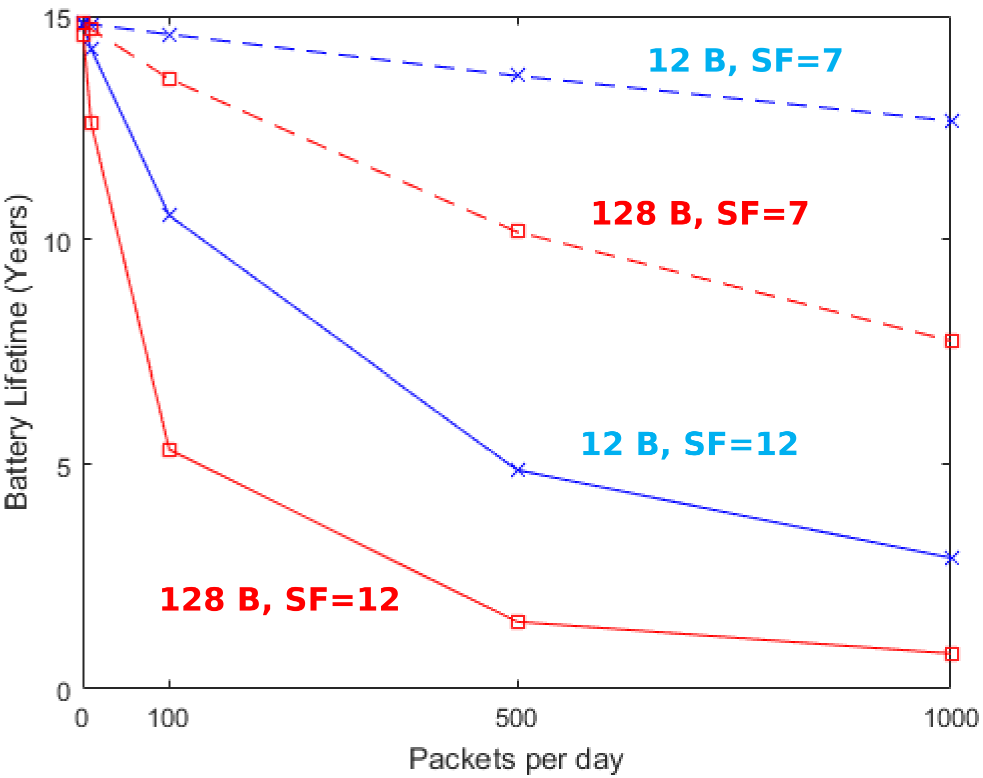
Spreading Factor (SF)	Bit Rate
SF=12	250 bps
SF=11	440 bps
SF=10	980 bps
SF=9	1.7 Kbps
SF=8	3.1 Kbps
SF=7	5.4 Kbps

Range

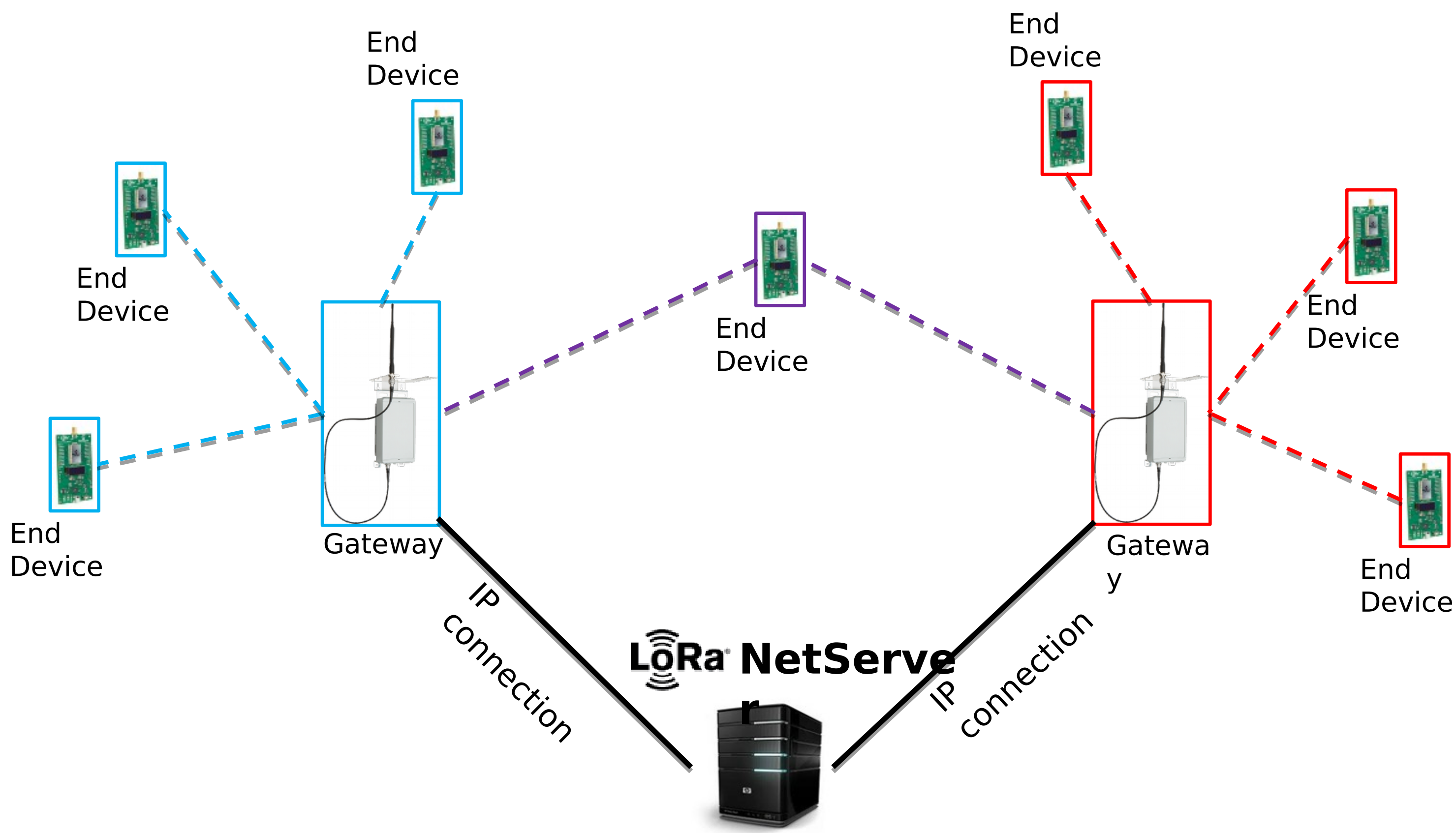
for a duty cycle of 1%

LoRa: Battery life

- Transmission power: 14 dBm
- Battery: 19 Ah (size D)
  - $26
- Voltage: 3.6 V
- Platform idle consumption: 0.1 mA



LoRaWAN Network Architecture

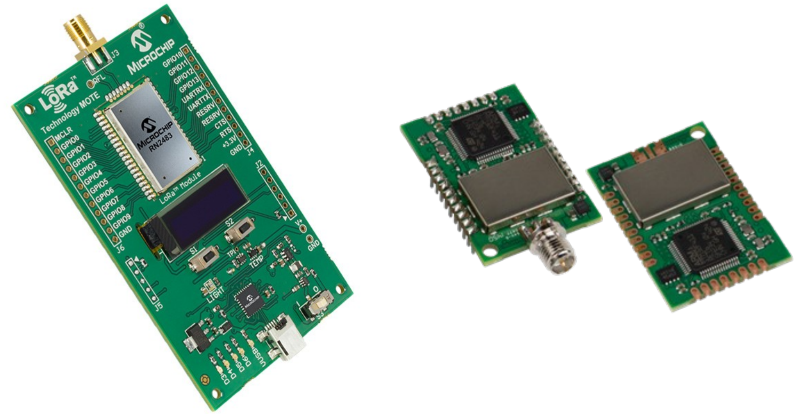


LoRaWAN elements

- LoRa Gateway:
  - Maintains radio connectivity
  - Acts as transparent bridge
  - More than one gateway per end device is possible
  - Enables seamless network upgrade

- LoRa Server:
  - Maintains association with end node
  - Configures data rates
  - Removes duplicates
  - Handles security and access control
  - Interfaces with applications

LoRa devices



- Devices
  - Based on Semtech chip

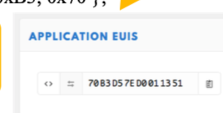
Heltec_LoRa_example.ino

```
#define USE_JOINING

#ifdef USE_JOINING
 // OTAA join keys
 // This EUI must be in little-endian format, so least-significant-byte
 // first. When copying an EUI from ttnctl output, this means to reverse
 // the bytes. For TTN issued EUIs the last bytes should be 0xD5, 0xB3,
 // 0x70.
 static const u1_t PROGMEM APPEUI[8] = { 0x51, 0x13, 0x01, 0xD0, 0x7E, 0xD5, 0xB3, 0x70 };
 void os_getArtEui (u1_t* buf) {
  memcpy_P(buf, APPEUI, 8);
 }

 // This should also be in little endian format, see above.
 static const u1_t PROGMEM DEVEUI[8] = { 0xF3, 0xA1, 0x29, 0xA9, 0x99, 0x0D, 0xF0, 0x00 };
 void os_getDevEui (u1_t* buf) {
  memcpy_P(buf, DEVEUI, 8);
 }

 // This key should be in big endian format (or, since it is not really a
 // number but a block of memory, endianness does not really apply). In
 // practice, a key taken from ttnctl can be copied as-is.
 // The key shown here is the semtech default key.
 static const u1_t PROGMEM APPKEY[16] = { 0x1F, 0x7E, 0xF5, 0x99, 0x43, 0x62, 0x8B, 0x2D, 0x88,
0x6A, 0xF6, 0xCE, 0x46, 0xCD, 0x05, 0x4E };
 void os_getDevKey (u1_t* buf) {
  memcpy_P(buf, APPKEY, 16);
 }
```

Defined to use Joinning (OTAA)

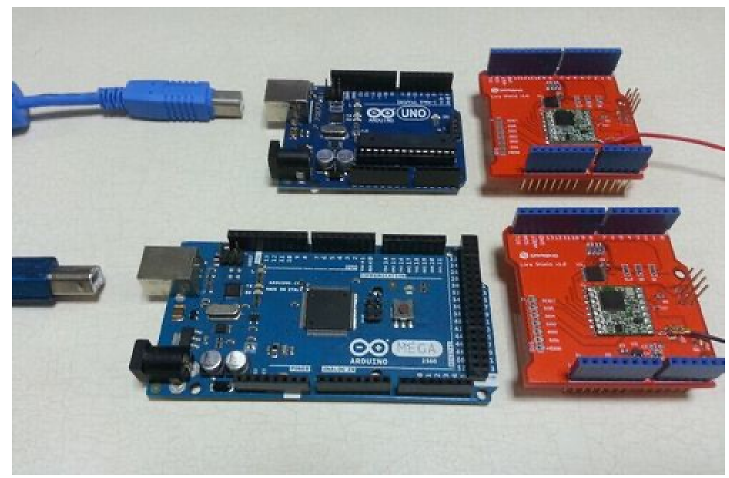
See the master_app application defined at TTN

AppEUI: Application identification



DevEUI: See the value on the TTN console once the device has been created

DevEUI: See the value on the TTN console once the device has been created



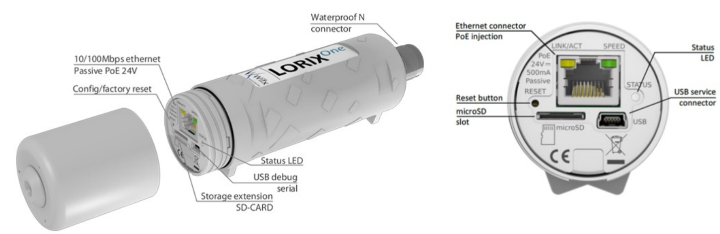
Arduino with Dragino LoRa Shield

LoRa Gateways

❑ Packet Forwarder

```
"radio_0": {
       "enable": true,
       "type": "SX1257",
       "freq": 867500000,
       "rssi_offset": -166.0,
       "tx_enable": true
}

"chan_multiSF_0": {
       /* Lora MAC channel, 125kHz, all SF,
868.1 MHz */
       "enable": true,
       "radio": 1,
       "if": -400000
}

"gateway_conf": {
    "gateway_ID": "AA555A0000000002",

//TTN SERVER
    "server_address":
"router.eu.thethings.network",
    "serv_port_up": 1700,
    "serv_port_down": 1700,
```

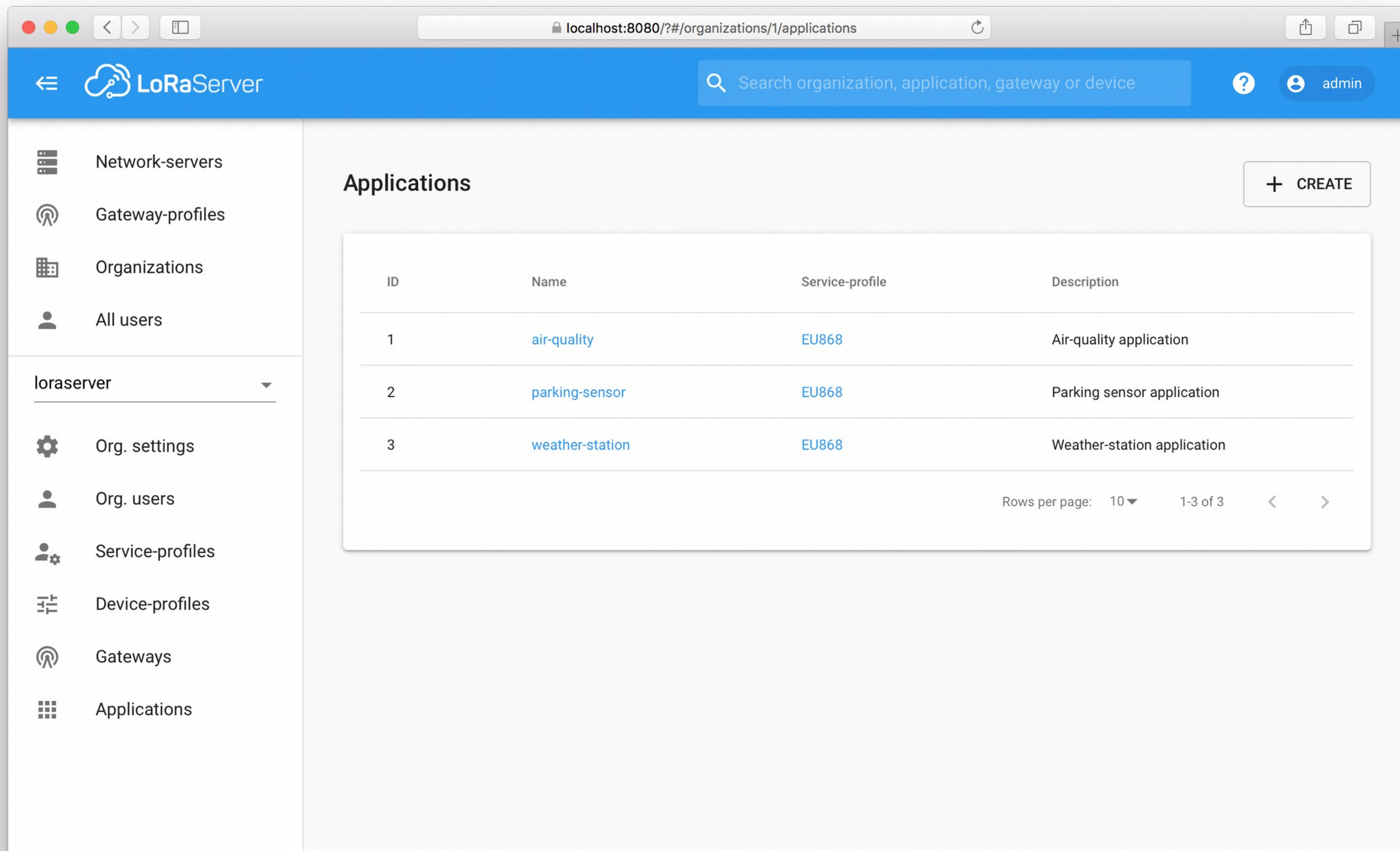
Details (IP43 and IP65 version)



Dimensions (IP43 and IP65 version)

LoRa Server

- Install your own LoRa Server

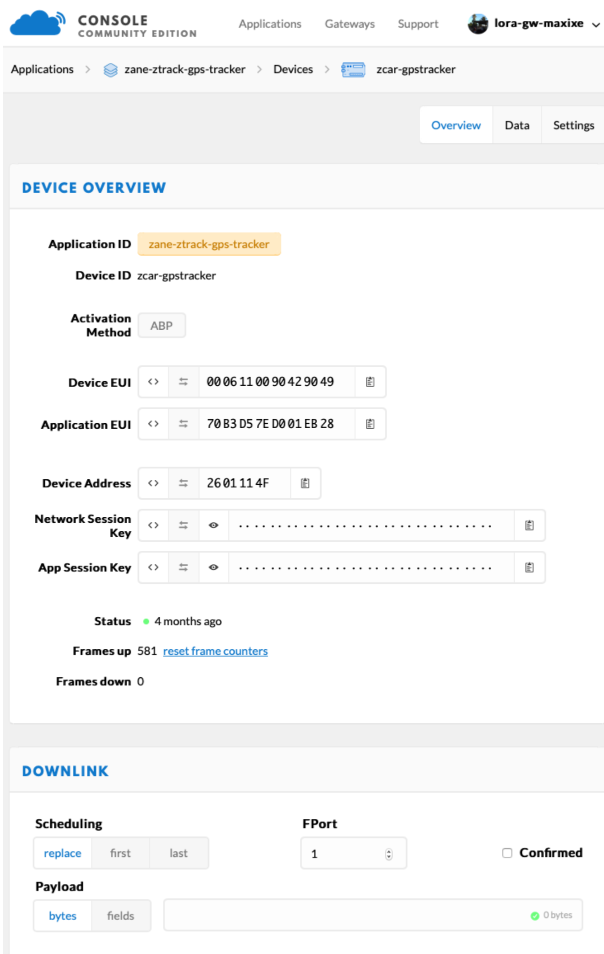


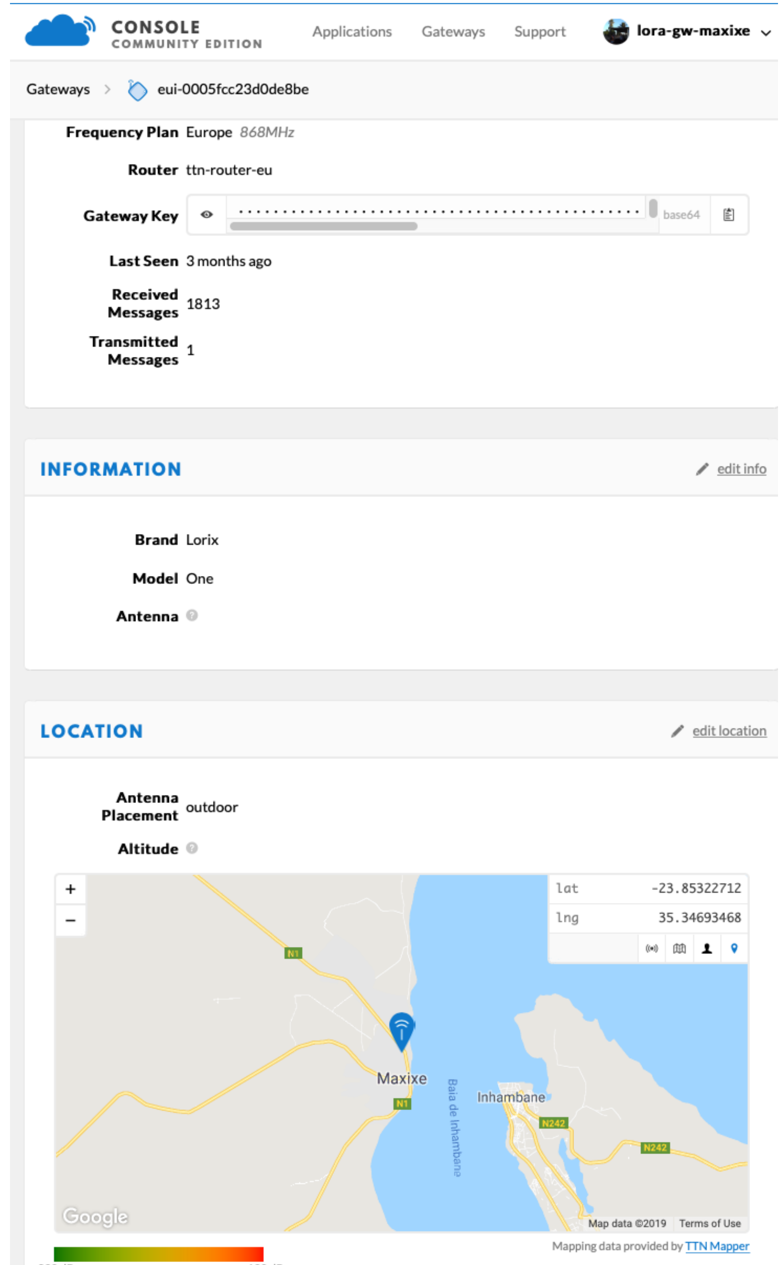
UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

UPC - UNQ

LoRa Server

- Use The Things Network server (TTN)

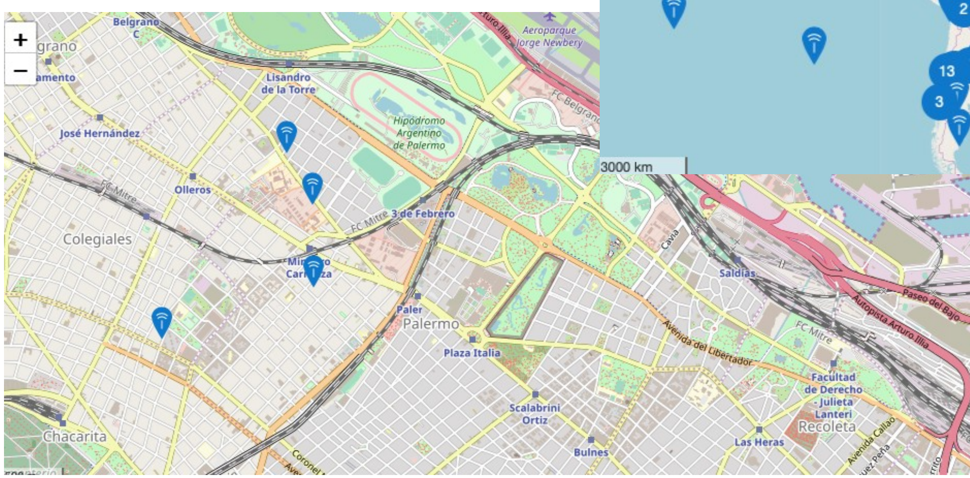




LoRa initiative

- Building a community network for IoT

THE THINGS
NETWORK



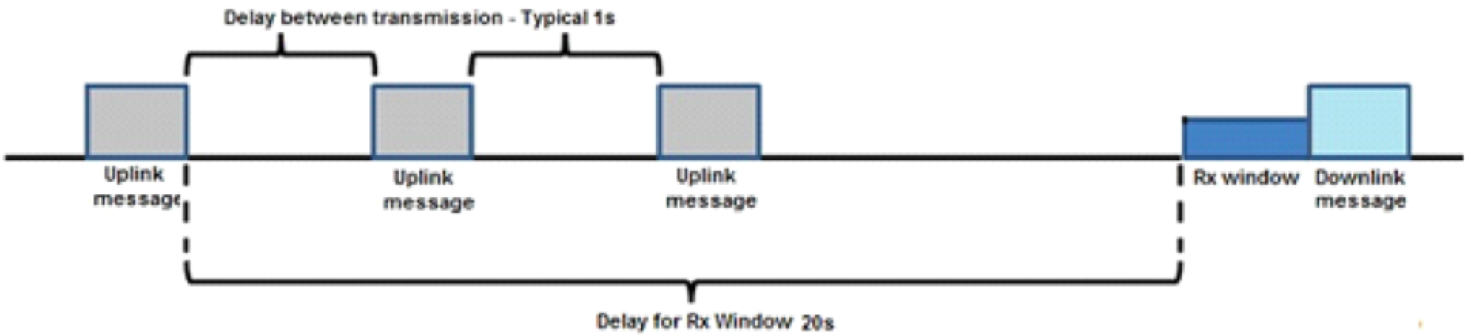
Sigfox

Sigfox

- Developed by a French company
  - Patented technology, several chip manufacturers
- Ultra Narrow Band (100 Hz in EU and 600 Hz in US)
- Bit Rate: 100 bps
  - Other bits are claimed to be possible (up to 1 Kbps)
- Up to 140 messages per day
- Maximum message size: 12 bytes
- ACKs are optional, up to 4 per day

Sigfox transmission

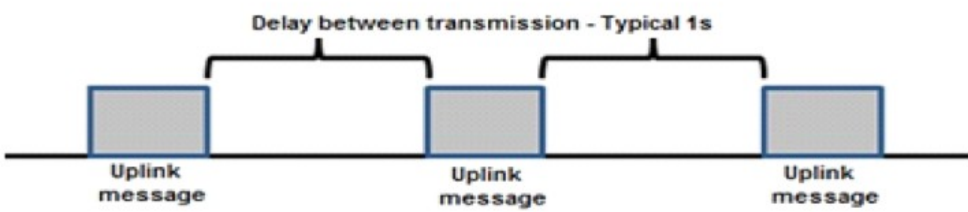
- Acknowledged. Up to 4 ACKs per day



8 Bytes

- Unacknowledged

12 Bytes



Sigfox

- Range
  - From 30 to 50 Km in rural areas
  - From 3 to 10 Km in urban areas
- Power consumption
  - Transmitted power
    - From -20 to +20 dBm
  - Required current
    - From 40 to 300 mA while transmitting
  - Example:
    - Libelium Sigfox 868

State	Power Consumption
OFF	0 mA
Transmitting data	~ 52 mA
Receiving data	~ 13 mA

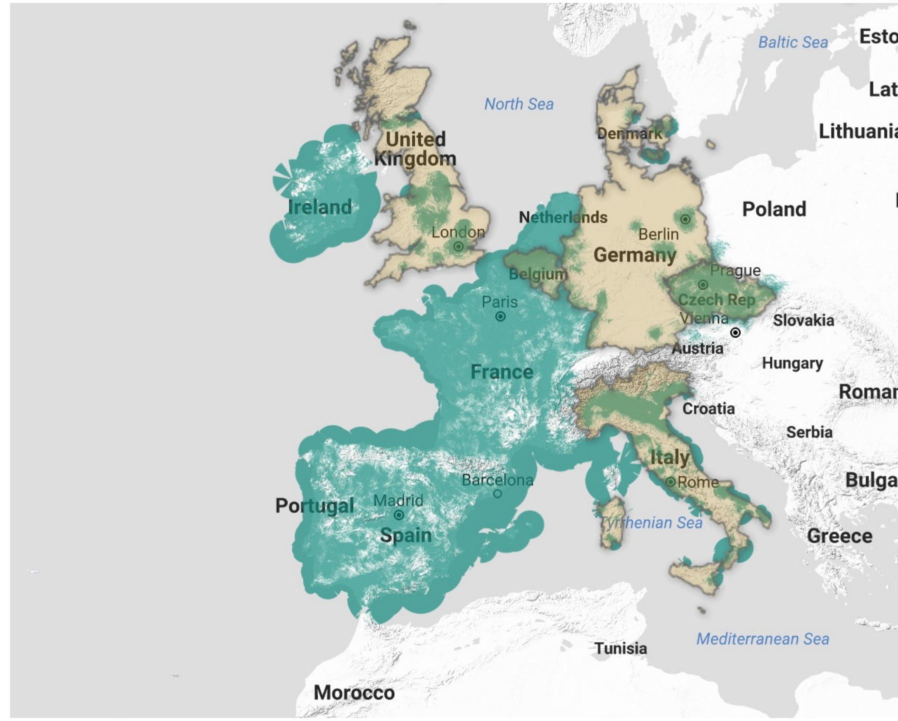
    - Libelium Sigfox 900

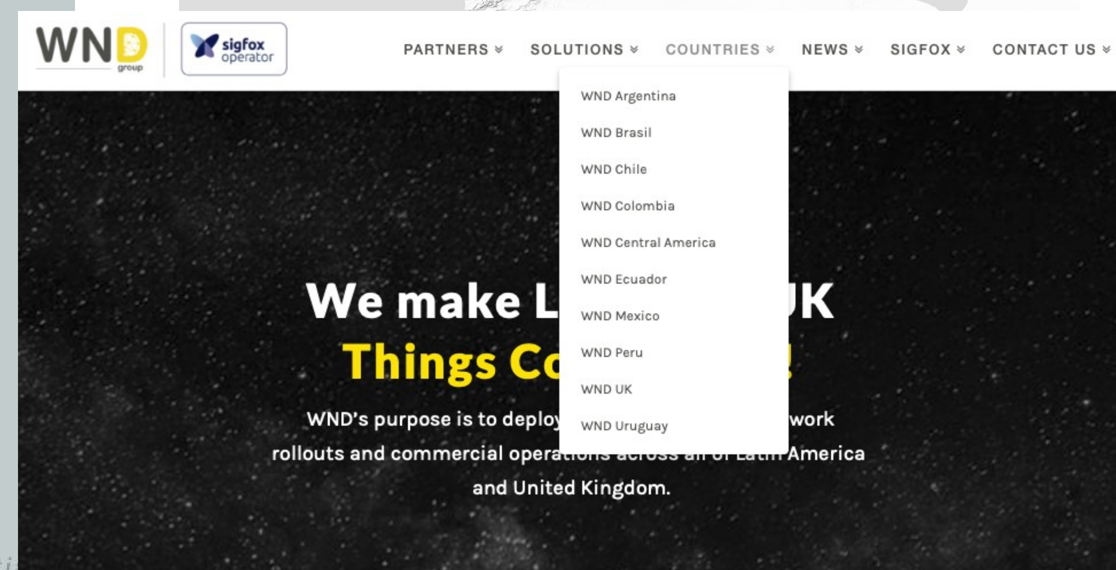
State	Power Consumption
OFF	0 mA
Transmitting data	~ 230 mA
Receiving data	~ 13 mA

UPC - UNQ

Sigfox coverage

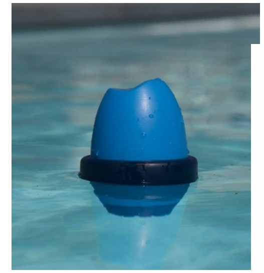
- Operator in Spain
  - Cellnex
- Operator in Argentina
  - WND





Devices

- Some examples
  - Field coverage
  - Pool analyzer
  - Water meter
  - Defibrillator
  - Livestock monitor
  - Parking monitor
  - Waste monitor
  - ....



UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

UPC - UNQ

Sigfox

- Received messages
  - Can be received by more than one base station

page 1

Time	Delay (s)	Header	Data / Decoding	TAP	RSSI (dBm)	Signal (dB)	Freq (MHz)	Rep	Callbacks
2014-06-11 17:30:45	1.1	0000	0000000000000000001a0c62	0985	-125.70	12.79	868.1911	2	
				0909	-137.40	6.96	868.1857	2	
				06FC	-110.00	8.73	868.1902	3	
2014-06-11 10:12:16	< 1	0000	000000000000000000190c62	0776	-129.10	7.61	868.1901	1	
				06FC	-106.00	25.89	868.1857	2	
2014-06-11 10:11:49	2.3	0000	000000000000000000180c62	07F1	-125.70	12.61	868.1904	2	
				06FC	-110.00	28.51	868.1857	2	
2014-06-11 10:11:38	< 1	0000	000000000000000000190c62	070B	-125.70	5.83	868.1853	1	
				06FC	-105.00	26.68	868.1913	3	
2014-06-11 10:11:25	< 1	0000	000000000000000000180c62	070B	-125.70	8.55	868.1901	1	
				06FC	-104.00	27.07	868.1903	3	

Cellular IoT (CIoT)

CIoT Requirements

- Be competitive in front arriving LPWAN (Sigfox, LoRa, ...)
  - Cheaper chips in comparison to 2G/3G/4G
  - Lower complexity
  - Duration of the battery up to 10 years
  - Lower power
  - Better range
  - Cover deep-indoor
  - Security: Using SIM
  - Safety: Using a licensed band

- Three options:
  - EC-GSM: Extended Coverage GSM
  - LTE-M: LTE Machine
  - NB-IoT: Narrow Band IoT

EC-GSM: Extended Coverage GSM

- EC-GSM: Extended Coverage GSM
  - GSM still dominant technology
  - Increases coverage up to 20 dB respect to GPRS
  - Capacity of up to 50.000 devices with a single transceiver
  - Range: less than 15 Km
  - Bit rate: 10 Kbps
  - Low cost

LTE-M: LTE Machine

- LTE-M: LTE Machine type communication
  - Also know as Category M (Cat-M1) or eMTC (enhanced Machine Type Communications)
  - Power saving mode
  - Extend battery life for LTE-M to 10 years or more
    - eDRX: extended discontinuous reception
    - Limits transmission power to 20 dBm
  - Reduced device cost
  - Extending the range with additional link budget of 15 dB
    - Range: 10 Km
  - Bit rate: 1 Mbps
  - Packet size: Between 100 and 1000 Bytes

NB-IoT: Narrow Band IoT

- NB-IoT: Narrow Band IoT
  - Each 200 KHz carrier can support more than 200.000 subscribers
  - Reduces control packets: lean carrier or lean procedures
  - Extended coverage up to 20 dB
    - Range: 15 Km
  - Bit rate: 150 Kbps
  - Battery saving features
    - Transmission power limited to 20 dBm
  - NB-IoT device complexity simpler than LTE-M
    - No additional power amplifier is required

Ericsson: Cellular networks for massive IoT

Data Management Platforms

Huge amount of data needs to be stored, processed and analysed

The Things Network: LoRa

Things Board

Thing Speak: MATLAB oriented

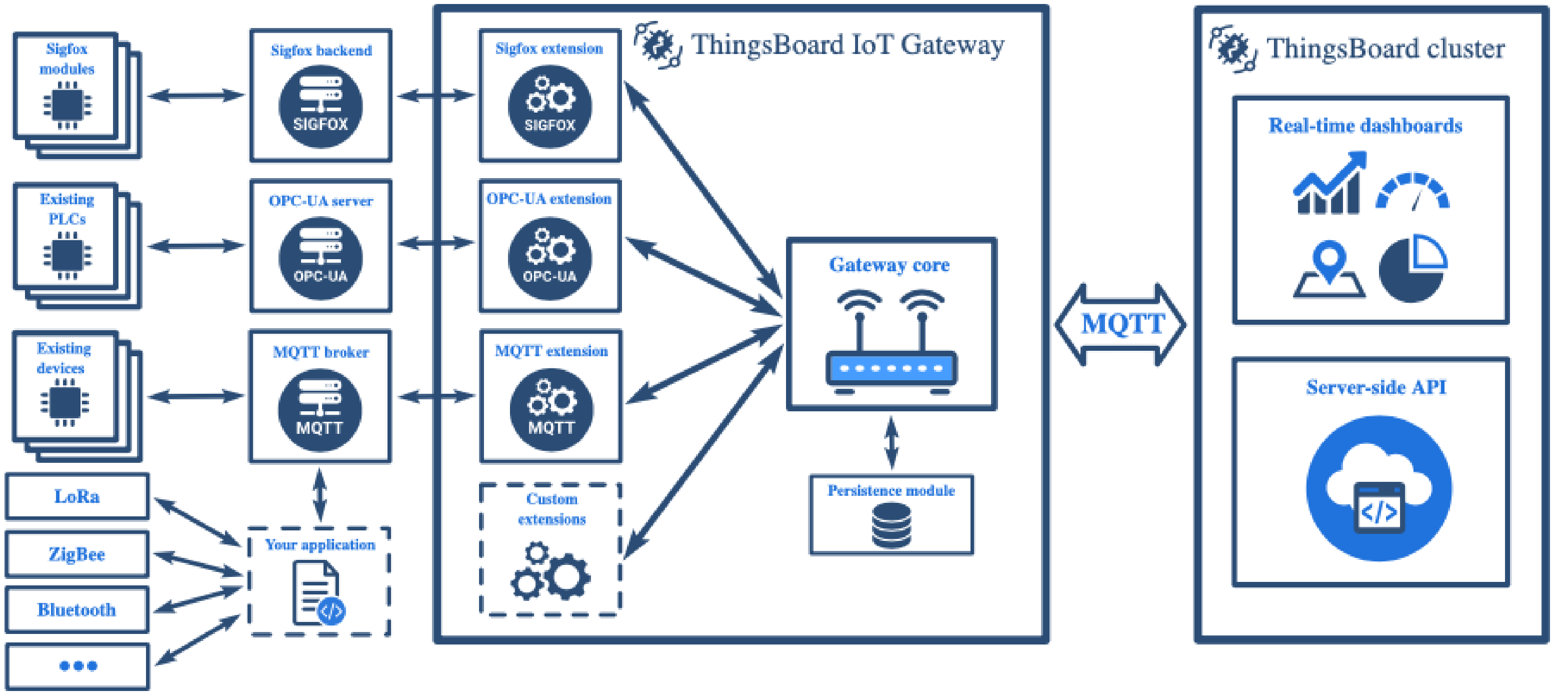
...

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

UPC - UNQ

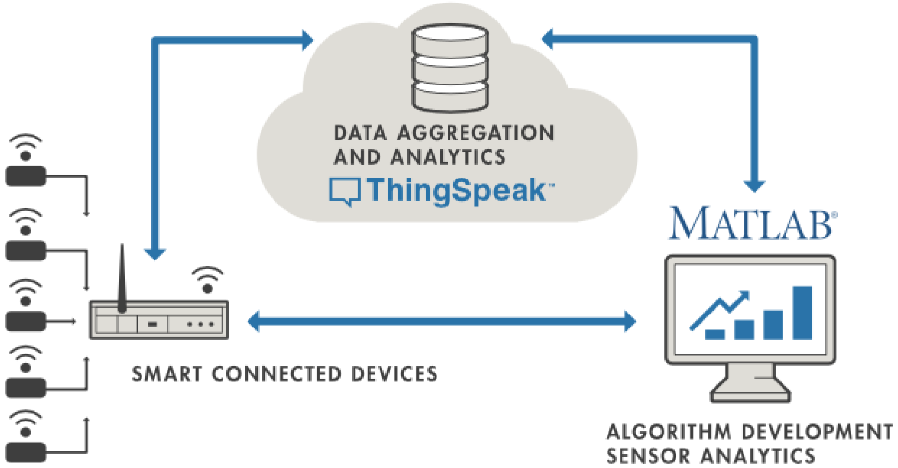
ThingsBoard Architecture

- Open-source IoT platform
- Enables rapid development, management and scaling of IoT projects
- Provides out-of-the-box IoT cloud or on-premises solution that will enable server-side infrastructure for your IoT applications



ThingSpeak

- IoT analytics platform service that allows:
  - Aggregate, visualize, and analyse live data streams in the cloud You can send data to ThingSpeak from your devices, create instant visualizations of live data, and send alerts using web services like Twitter
  - With MATLAB analytics inside ThingSpeak, you can write and execute MATLAB code to perform pre-processing, visualizations, and analyses



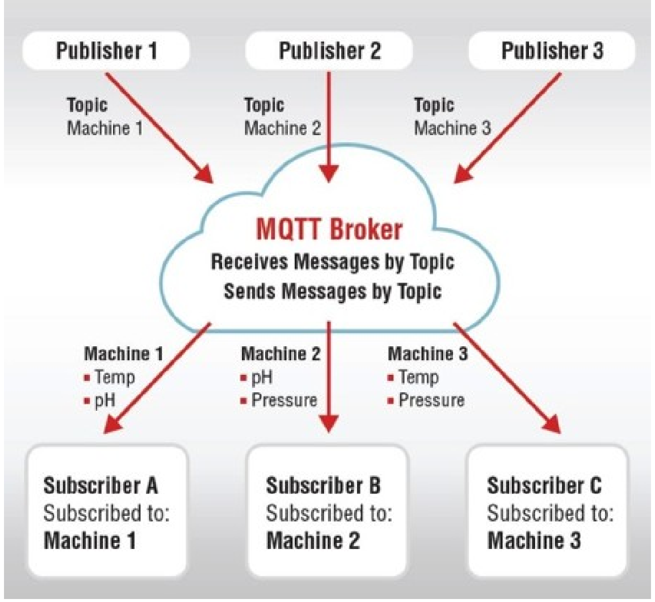
MQTT: Message Queuing Telemetry Transport

- Oasis standard
  - Non-profit consortium that drives the development, convergence and adoption of open standards for the global information society
- Machine-to-machine connectivity protocol
  - Lightweight and simple
  - Agnostic to the content of the payload
  - Small transport overhead and protocol exchanges minimized to reduce network traffic
  - A mechanism to notify interested parties when an abnormal disconnection occurs.
- Runs over TCP/IP, or over other network protocols that provide ordered, lossless, bi-directional connections
- Uses the publish/subscribe message pattern which provides one-to-many message distribution and decoupling of applications

MQTT: Message Queuing Telemetry Transport

- MQTT is based on a publish-subscribe structure:
  - A Publisher sends messages according to Topics, to specified Brokers
  - A Broker acts as a switchboard, accepting messages from publishers on specified topics, and sending them to subscribers to those Topics
  - A Subscriber receives messages from connected Brokers and specified Topics

mosquitto



MQTT Pub/Sub

- Clients connect to a “Broker”
- Clients subscribe to topics:
  - `client.subscribe(‘toggleLight/1’);`
  - `client.subscribe(‘toggleLight/2’);`
  - `client.subscribe(‘toggleLight/3’);`
- Clients can publish messages to topics:
  - `client.publish(‘toggleLight/1’, ‘toggle’);`
  - `client.publish(‘toggleLight/2’, ‘toggle’);`
- All clients receive all messages published to topics they subscribe to
- Messages can be anything:
  - Text
  - Images
  - etc

Name	Value	Direction of flow	Description
Reserved	0	Forbidden	Reserved
CONNECT	1	Client to Server	Connection request
CONNACK	2	Server to Client	Connect acknowledgment
PUBLISH	3	Client to Server or Server to Client	Publish message
PUBACK	4	Client to Server or Server to Client	Publish acknowledgment (QoS 1)
PUBREC	5	Client to Server or Server to Client	Publish received (QoS 2 delivery part 1)
PUBREL	6	Client to Server or Server to Client	Publish release (QoS 2 delivery part 2)
PUBCOMP	7	Client to Server or Server to Client	Publish complete (QoS 2 delivery part 3)
SUBSCRIBE	8	Client to Server	Subscribe request
SUBACK	9	Server to Client	Subscribe acknowledgment
UNSUBSCRIBE	10	Client to Server	Unsubscribe request
UNSUBACK	11	Server to Client	Unsubscribe acknowledgment
PINGREQ	12	Client to Server	PING request
PINGRESP	13	Server to Client	PING response
DISCONNECT	14	Client to Server or Server to Client	Disconnect notification
AUTH	15	Client to Server or Server to Client	Authentication exchange

UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

UPC - UNQ

Vehicular Networks

Jordi Casademont
jordi.casademont@upc.edu

Introduction

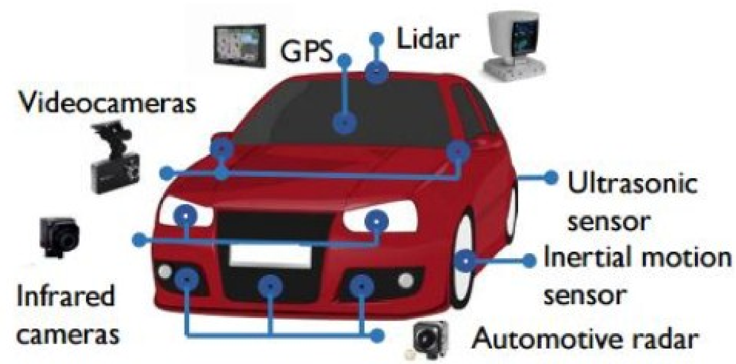
- What is V2X?
  - Enabling vehicles with wireless communication capabilities
  - To communicate with:
    - Other vehicles (V2V)
    - The infrastructures (V2I)
    - Pedestrians, bikes, scooters (Vulnerable Road Users)
    - Environment
    - Global Internet
    - ....
    - Everything (V2X)

Source: Volkswagen Golf 2020 Car2X

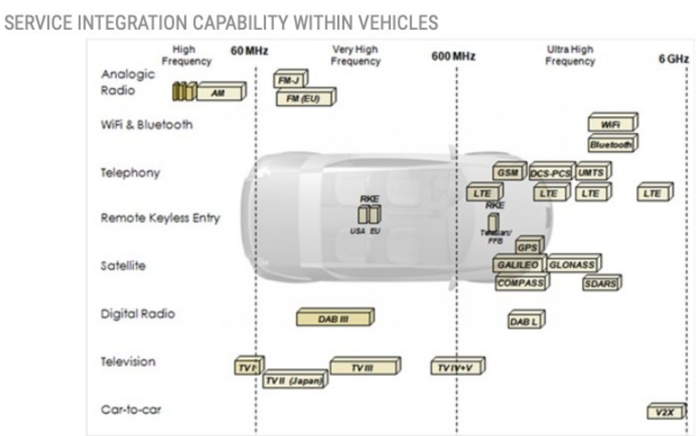
Source: Qualcom

Day 0: Local perception sensors

- Today, without communications
  - Vehicle knows about objects detected by its local sensors
  - Adaptive Cruise Control (ACC)
  - Front Collision Warning
  - Lane Departure Warning
  - Lane Change Assist
  - Park Distance Control
  - Park Assist



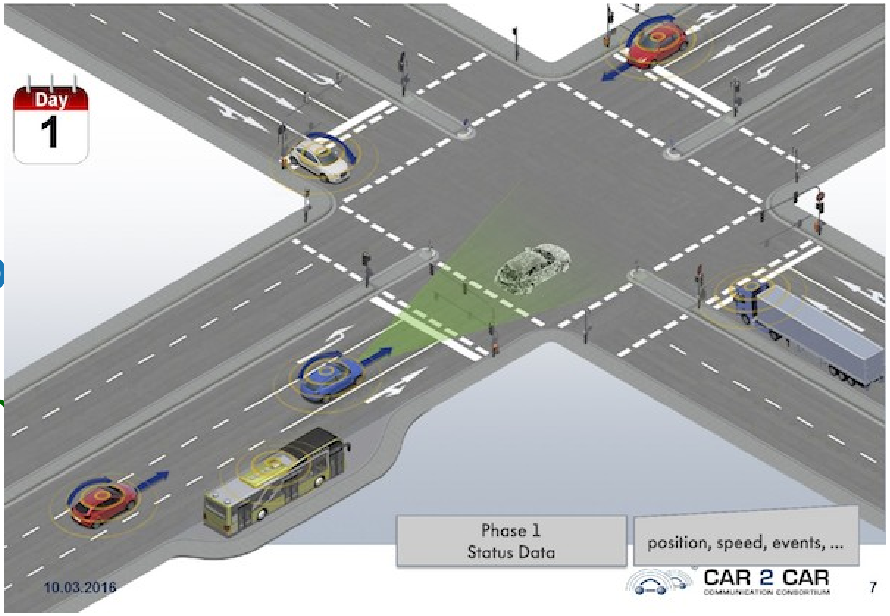
Source: Car2car



Source: Ficosa

Day 1: Awareness Driving

- Vehicle status data
  - Position
  - Speed
  - Events
- Infrastructure informatio
  - Traffic light phases
  - Speed recommendation
- Services
  - Traffic jam
  - Road works
  - Intersection collision warning
  - Emergency / stationary vehicle warning
  - Green Light Optimal Speed Advisory
  - In-Vehicle Information



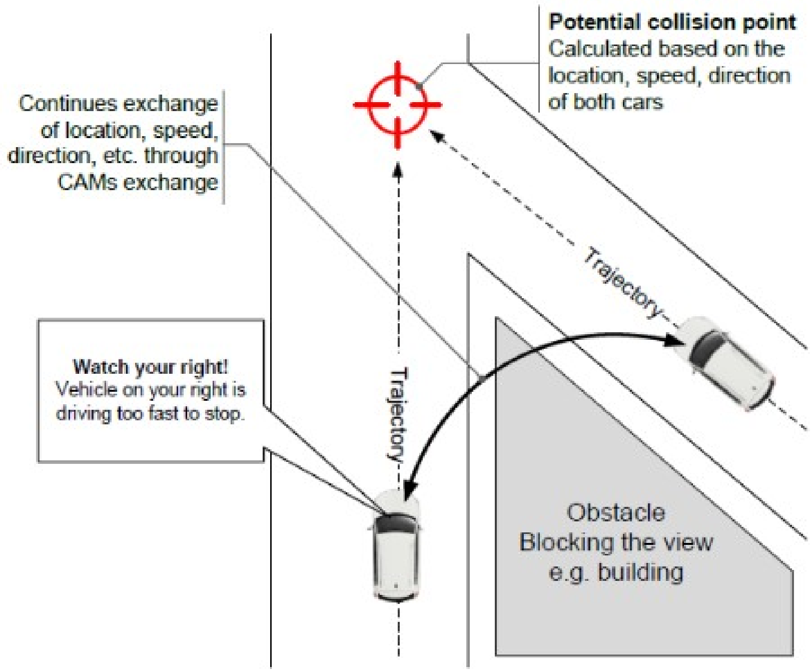
Cooperative Awareness Basic Service

- CAM: Cooperative Awareness Message

ETSI EN 302 637-2 V1.4.1 (2019-01)

  - SAE J2735: Basic Safety Message (BSM)

- Periodic messages sent by all stations giving information about status and attribute information of the originating device
  - Status: Time, position, motion state, activated systems, ...



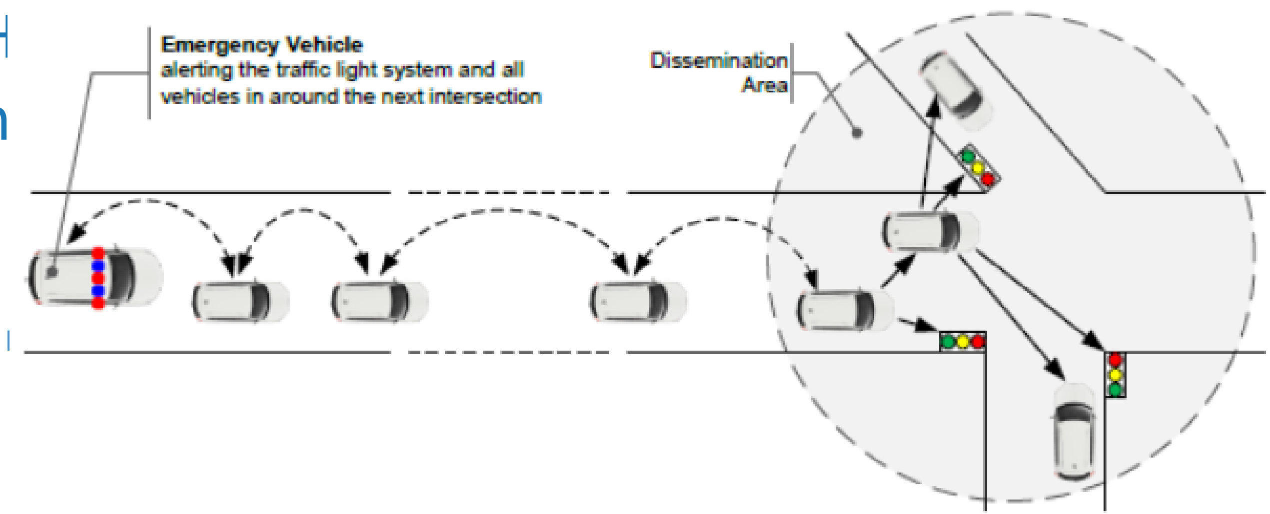
Decentralized Environmental Notification Basic Service

- DENM (Decentralised Environmental Notification Message)

ETSI EN 302 637-3 V1.3.0 (2018-08)

  - Event-driven messages sent by OBU/RSU upon detection of an abnormal situation (traffic jam, break down vehicle, roadworks ...) to alert other vehicles or road users within a geographical area

- Generation interval (as long as the event is present): 1 to 10 H
- V2V an



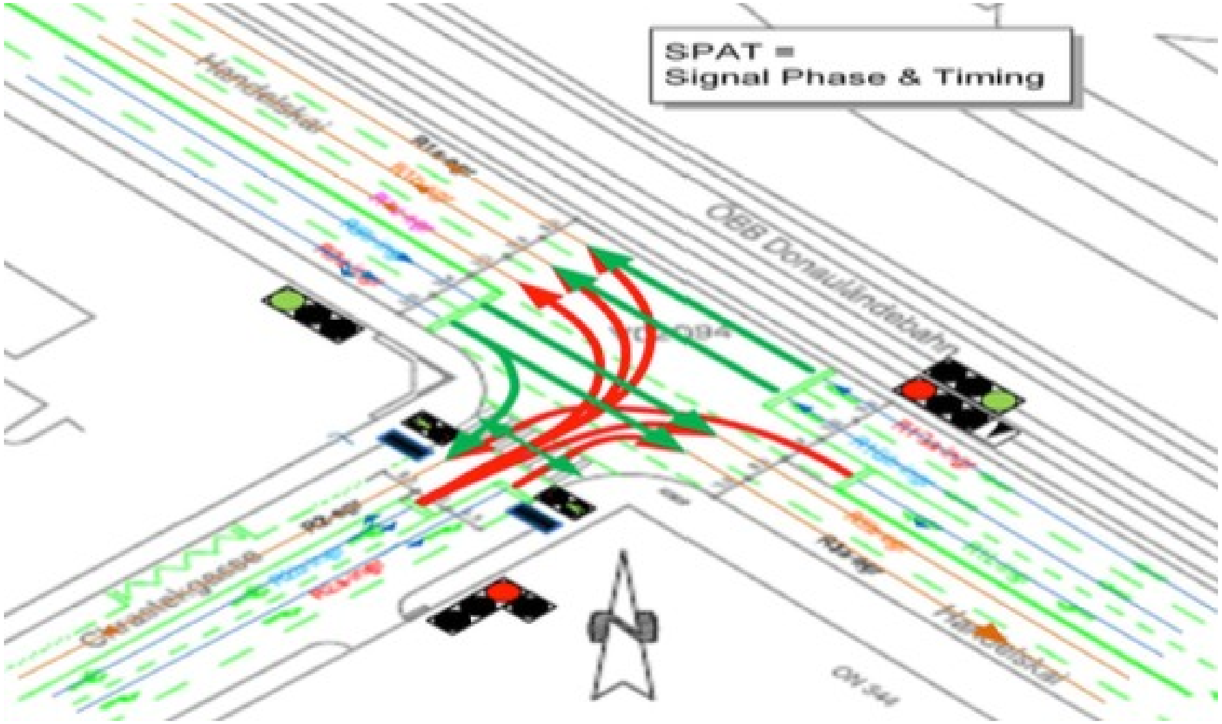
Traffic Light Manoeuvre (TLM) Service

- SPATEM (Signal Phase and Timing Extended Message)

ETSI EN 103 301 V1.2.1 (2018-08)

SAE J2735

  - SPATEM is SAE’s SPAT message with an additional ETSI header



UPC - UNQ

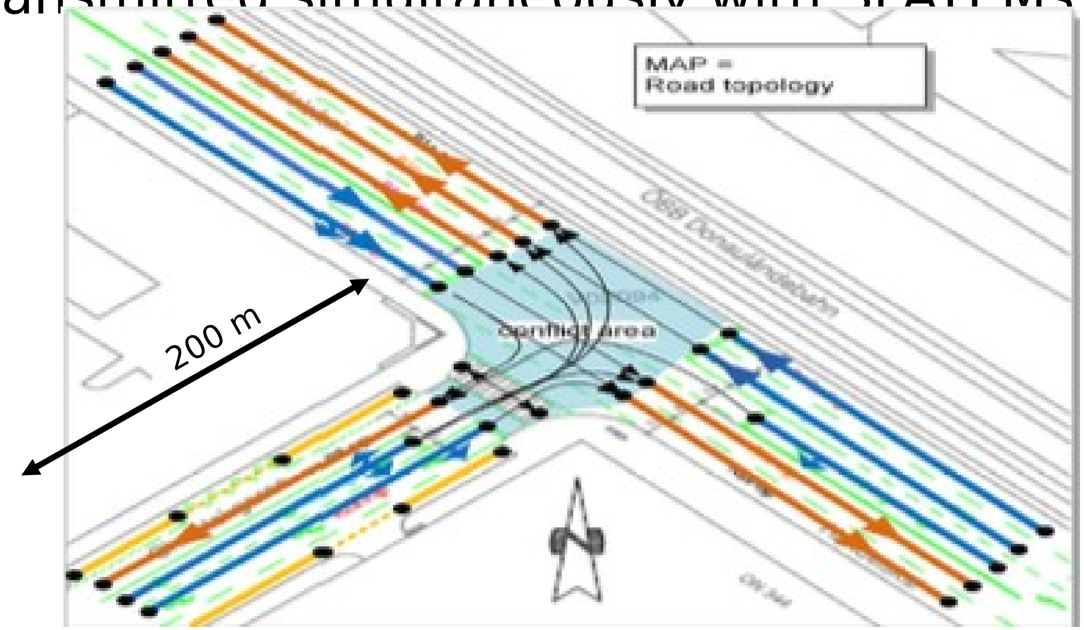
Road and Lane Topology (RLT) service

MAPEM (Map data Extended Message)

ETSI EN 103 301 V1.2.1 (2018-08)

SAE J2735

- MAPEM is SAE's MAP message with an additional ETSI header
  - Topological definition of lanes within an intersection or road-segment
  - Transmitted simultaneously with SPATEMs



Infrastructure to Vehicle Information (IVI) service

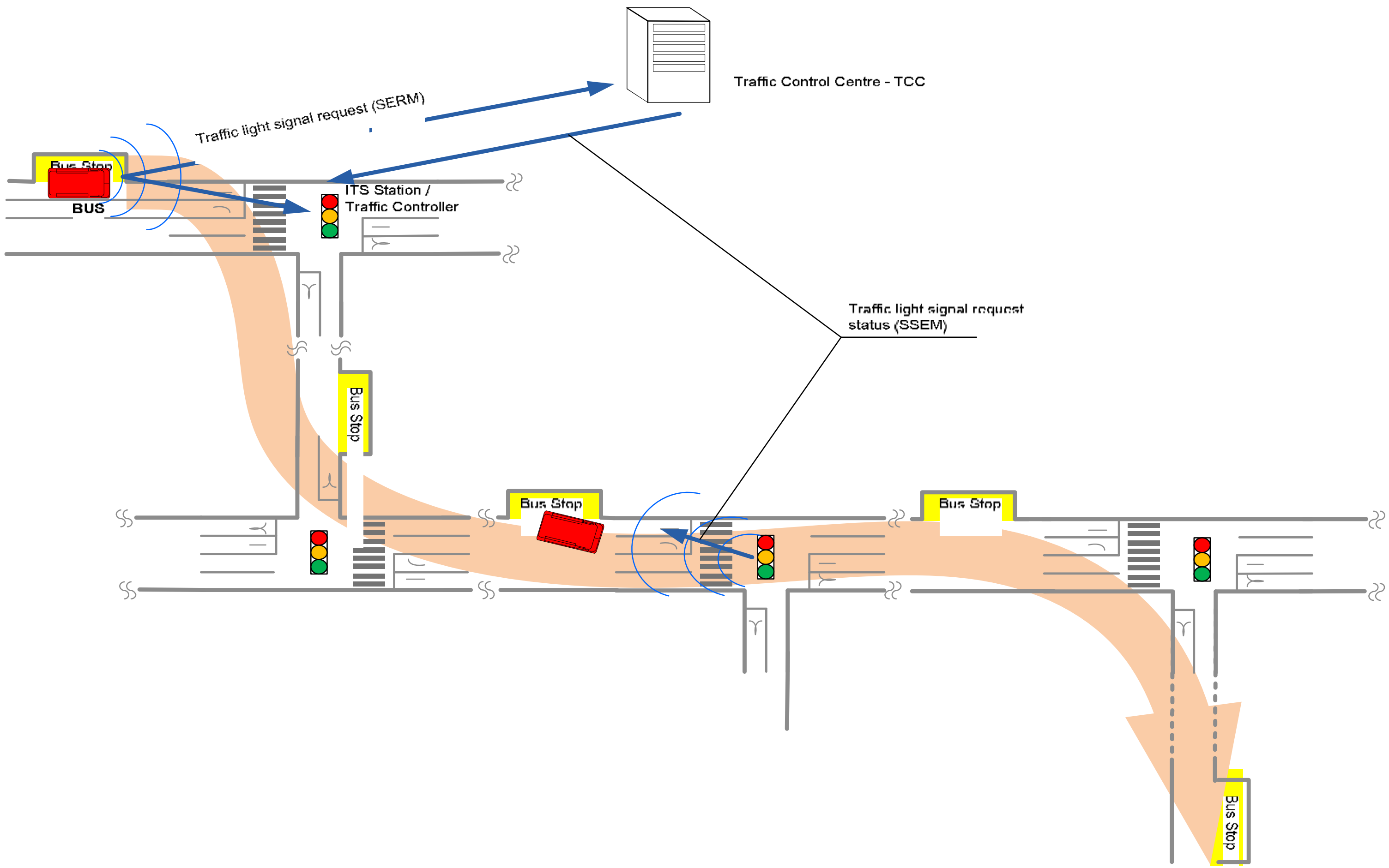
- Infrastructure broadcasts IVIM messages

ETSI EN 103 301 V1.2.1 (2018-08)

CEN ISO/TS 19321

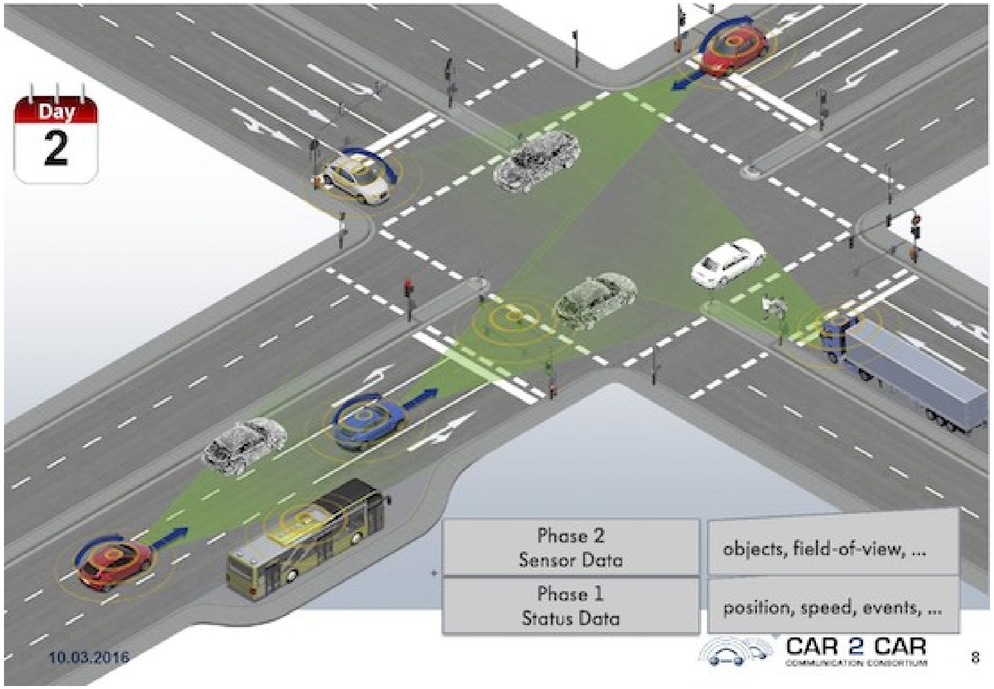
- IVIM supports mandatory and advisory road signage:
  - Contextual speeds
  - Road works warnings
  - Static or variable road signs

Traffic Light Control (TLC) Service

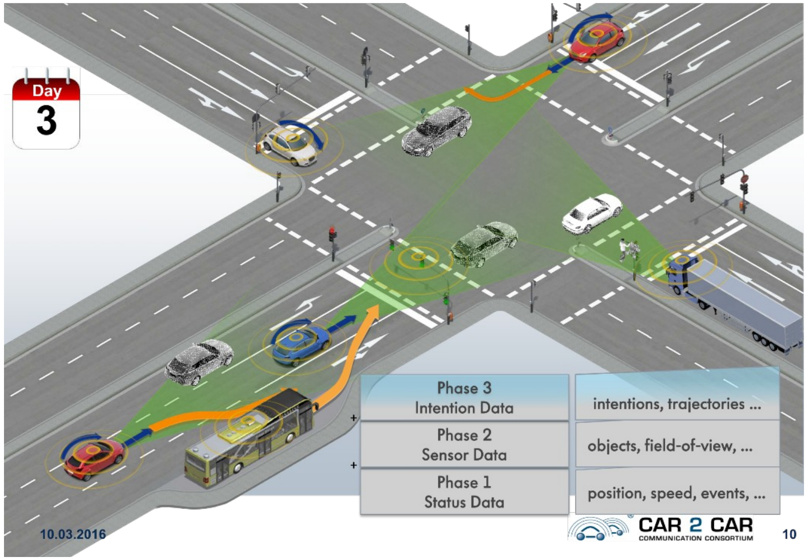


Day 2: Sensing Driving

- Collective perception
- Vehicles broadcast their locally perceived objects:
  - Sensor data
- Much more amount of data to transmit!!
- Services
  - Road works 2.0: triggered by vehicles
  - Overtaking warning
  - Connected ACC



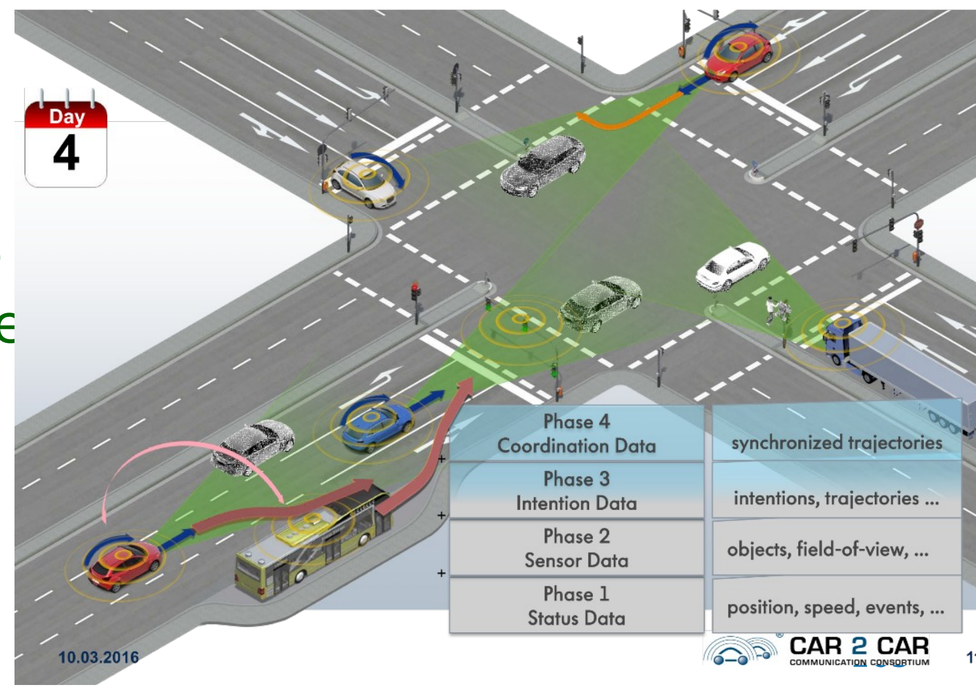
Day 3: Cooperative Driving



- Intention data ("My plan")
  - Vehicles send intended manoeuvres and trajectories
- Services
  - Lane-merging assistance
  - Cooperative ACC
  - Vulnerable Road User (VRU) warning
- Intentions are used by automated driving algorithms to enable vehicles to accurately predict what others will do and optimize their own decisions and actions

Day 4: Synchronized Cooperative Driving

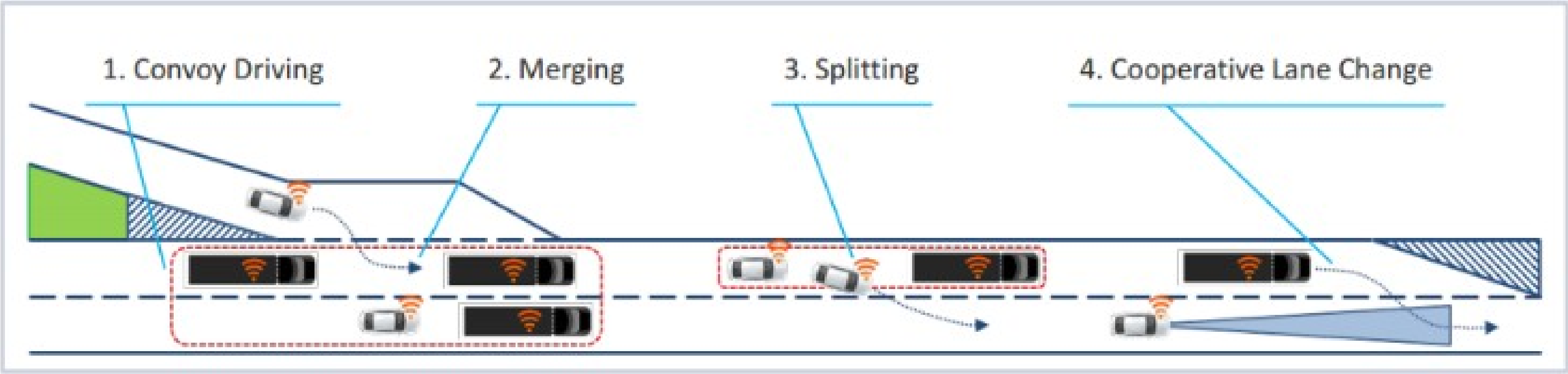
- Coordination data
  - Synchronized trajectories
  - Orders
- **Vehicles are autonomously driven** through almost all situations and are able to exchange and synchronize driving trajectories among each other
- Services
  - Cooperative merging
  - Overtaking assistance
  - Intersection assistance
  - Dynamic platooning
  - VRU assistance



Day 3 - 4: Cooperative Driving

- Use case: Platooning
  - V2X facilitates negotiating planned manoeuvres:
    - Merging
    - Creating gaps
    - Yielding right of way

http://news.mit.edu/2016/driverless-truck-platoons-save-time-fuel-1221



Service requirements for day 1-2 applications

- Proposed performance parameters

[ETSI TR 102 638 V1.1.1 2009-06. Intelligent Transport Systems (ITS); Vehicular communications; Basic Set of Applications; Definitions]

Safety Service	Use case	Min. frequency	Max. Latency
Vehicle status warning	Emergency electronic brake lights	10 Hz	100 ms
	Abnormal condition warning	1 Hz	100 ms
Traffic hazard warning	Wrong way driving warning	10 Hz	100 ms
	Traffic condition warning	1 Hz	100 ms
Dynamic vehicle warning	Overtaking vehicle warning	10 Hz	100 ms
	Pre-crash sensing warning	10 Hz	50 ms
Non-safety Service	**Use case**	**Min. frequency**	**Max. Latency**
Traffic Management	Speed limits	1 Hz	100 ms
	Traffic light optimal speed	2 Hz	100 ms

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Service requirements for day 3-4 applications

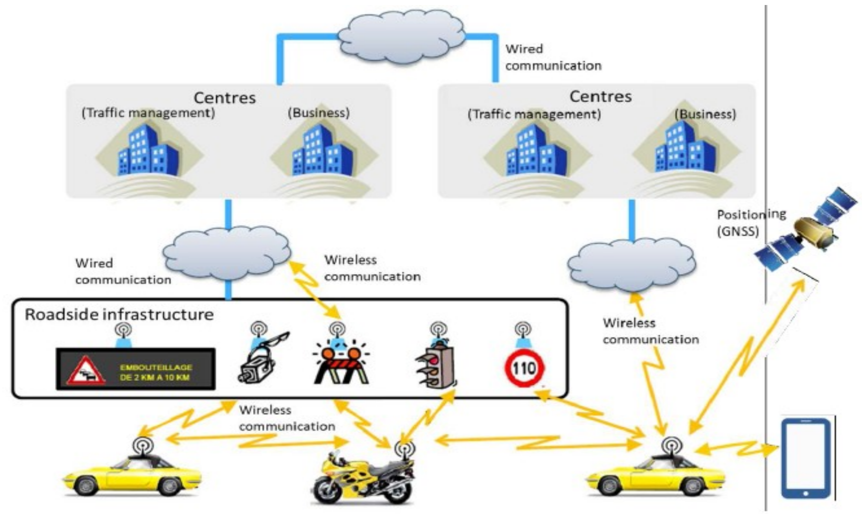
❑ Proposed performance parameters

[ETSI TS 122 186 V14.4.0 2018-10. 5G; Service requirements for enhanced V2X scenarios. (3GPP TS 22.186 version 15.40.0 Release 15]

Service	Tx rate (message/s)	Max. Latency (ms)	Data rate (Mbps)
Vehicles Platooning	30 to 50	10 to 20	up to 65
Advanced Driving	10 to 50	3 to 100	Up to 50
Sensor info sharing	10	3 to 100	10 to 1000
Video sharing		10 to 50	10 to 700
Remote Driving		5	25

Intelligent Transport System (ITS) Architecture

❑ Elements:



- On Board Unit (OBU)
  - Vehicular
  - Personal

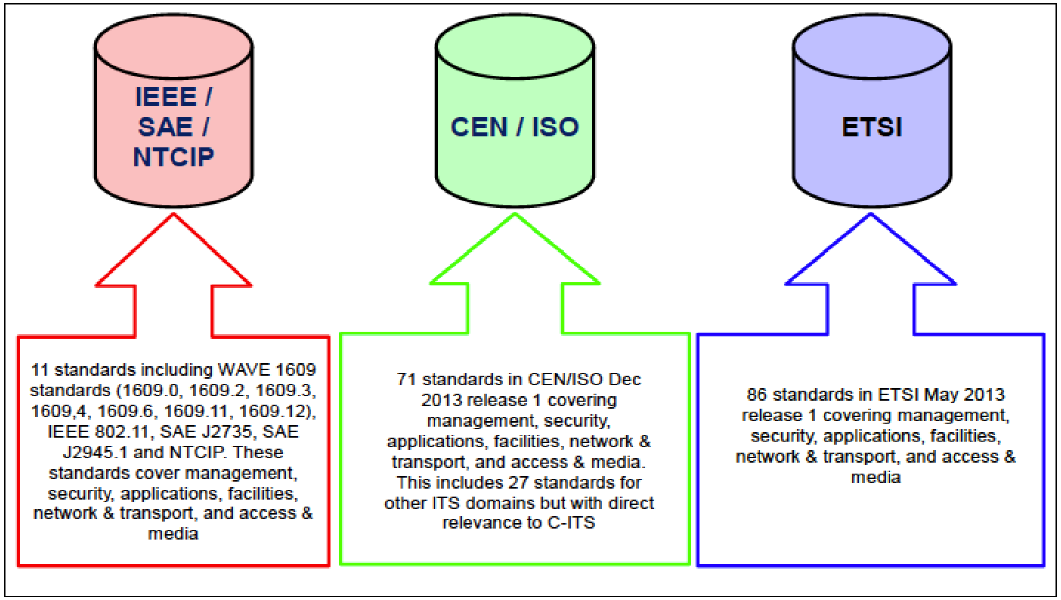
- Road Side Unit (RSU)

- Central ITS station
  - Provider's backoffice
  - Traffic management centres

Source: Ficosa

Standardization of communication protocols

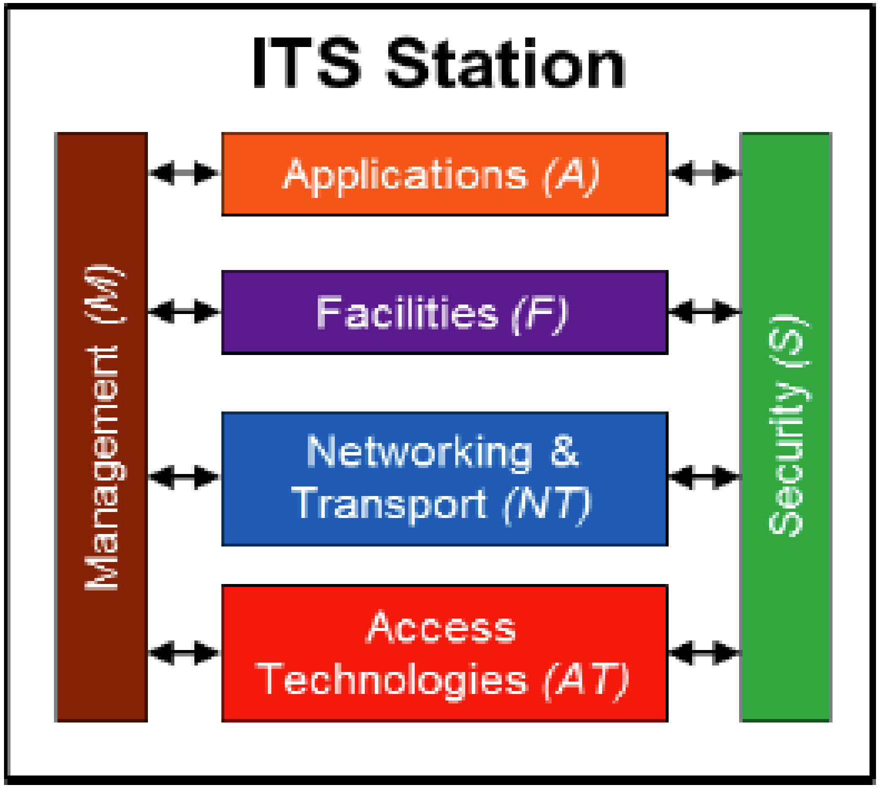
- 5 architectures:
  - International: CEN ISO
  - Europe: ETSI
  - America: IEEE, SAE, NTCIP
  - Korea
  - Japan: ARIB



- IEEE: Institute of Electrical and Electronics Engineers
- SAE: Society of Automotive Engineers
- NTCIP: National Transportation Communications for Intelligent Transportation System Protocol
- CEN: Comité Européen de Normalisation
- ISO: International Organization for Standardization

"Main" Protocol architecture

- New protocol stack



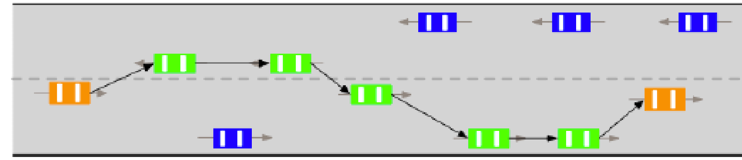
OSI Communication Protocols Stack

- Application
- Presentation
- Session
- Transport
- Network
- Link
- Physical

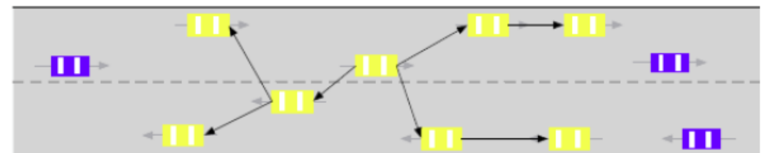
Forwarding in GeoNetworking

- Different types of forwarding based on the geographic position of the destination

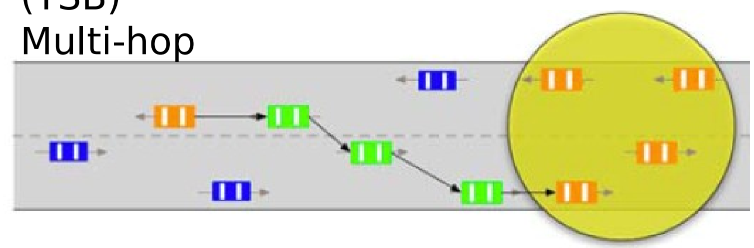
- Infrastructure operators interested in other



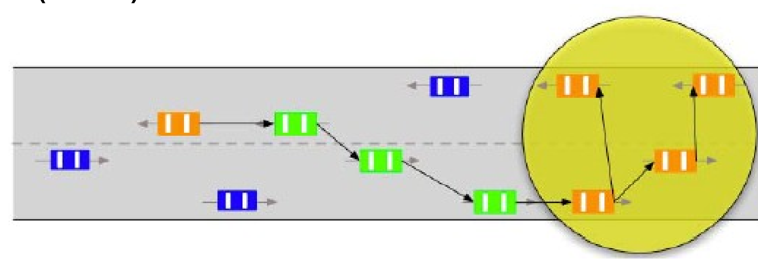
Geo-Unicast (GUC)



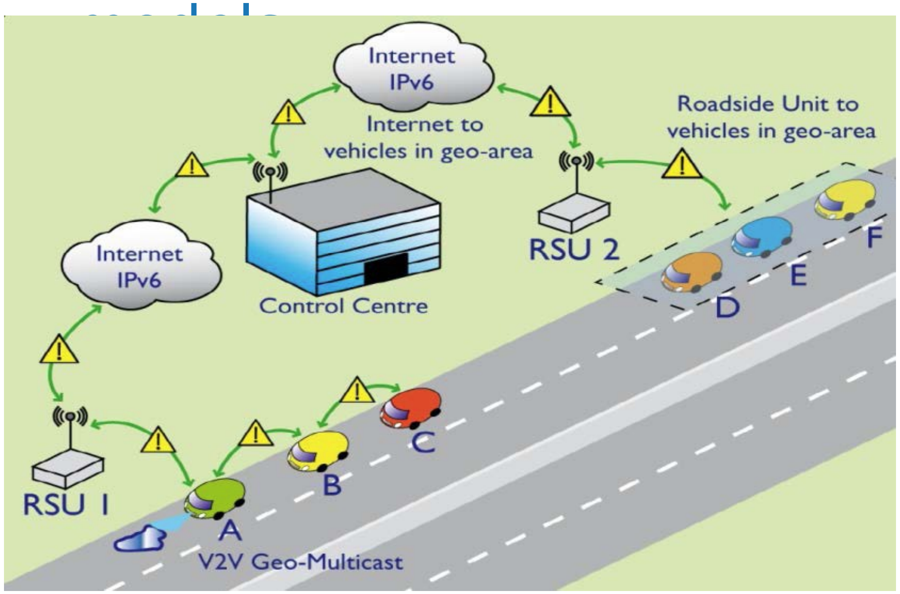
Topologically-Scooped Broadcast (TSB)
Multi-hop



Geographically-Scooped Anycast (GAC)



Geographically-Scooped Broadcast (GBC)



ITS security functional model

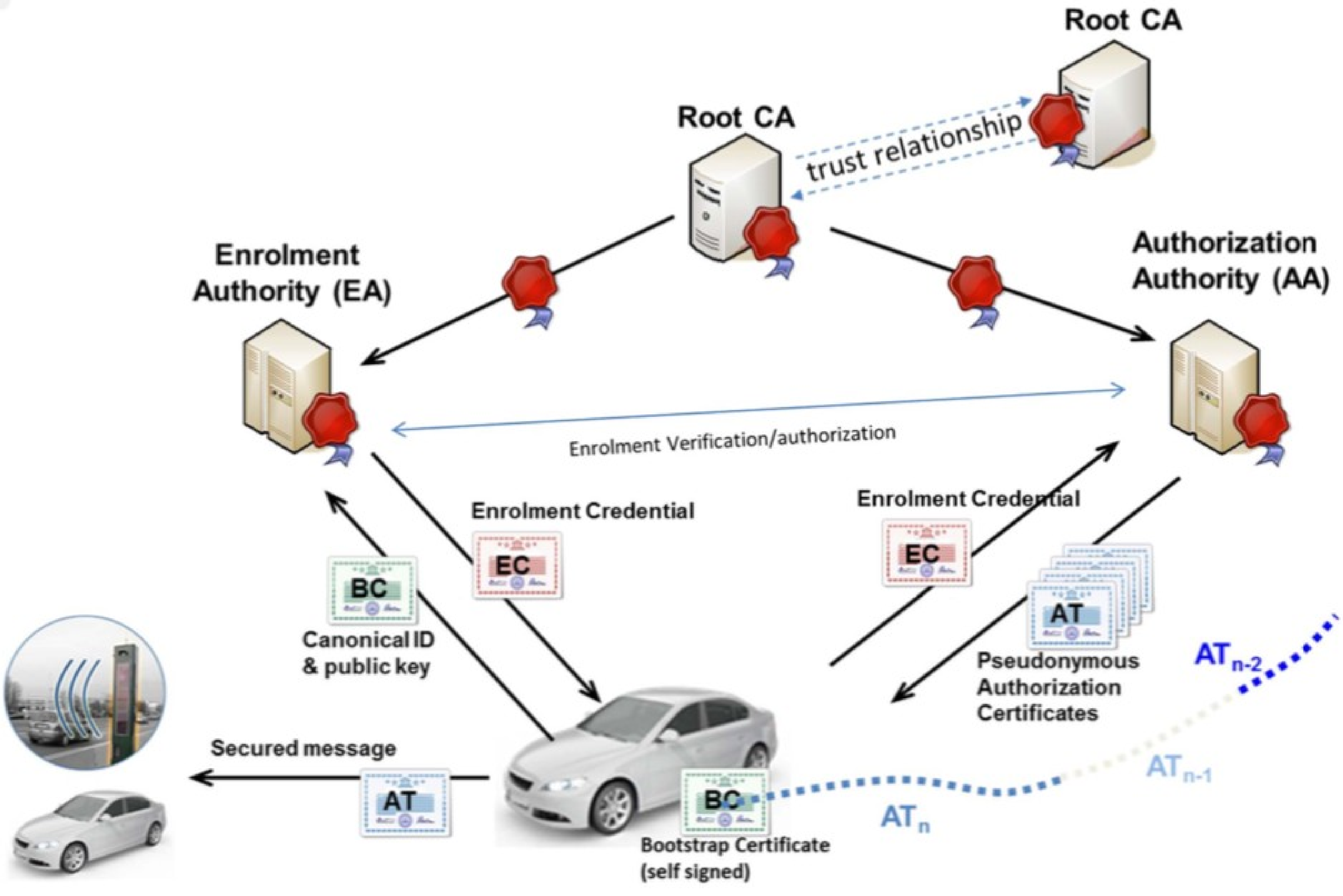
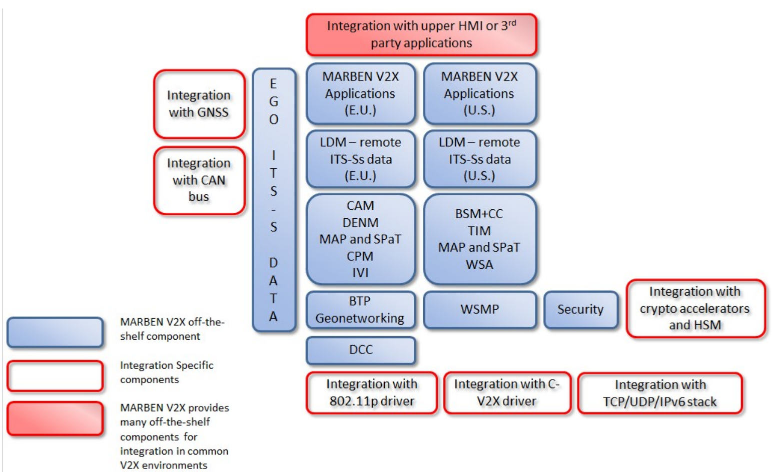


Figure 11: PKI architecture

New markets based on V2X communications

Source: www.v2x.network

V2X Software stack

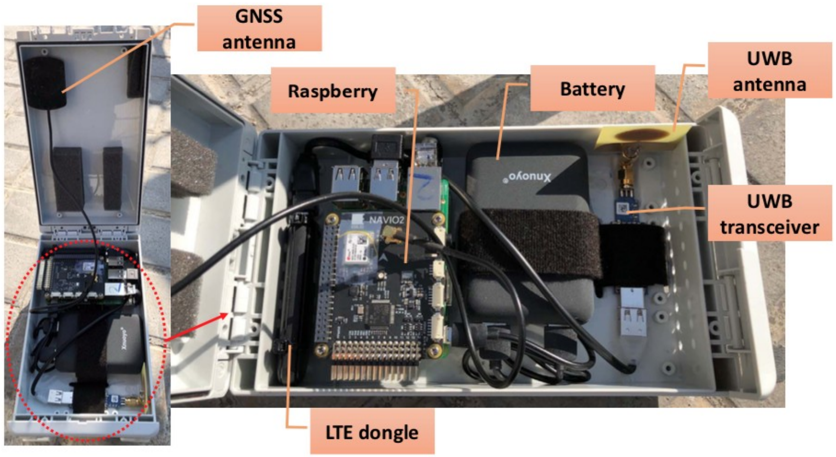


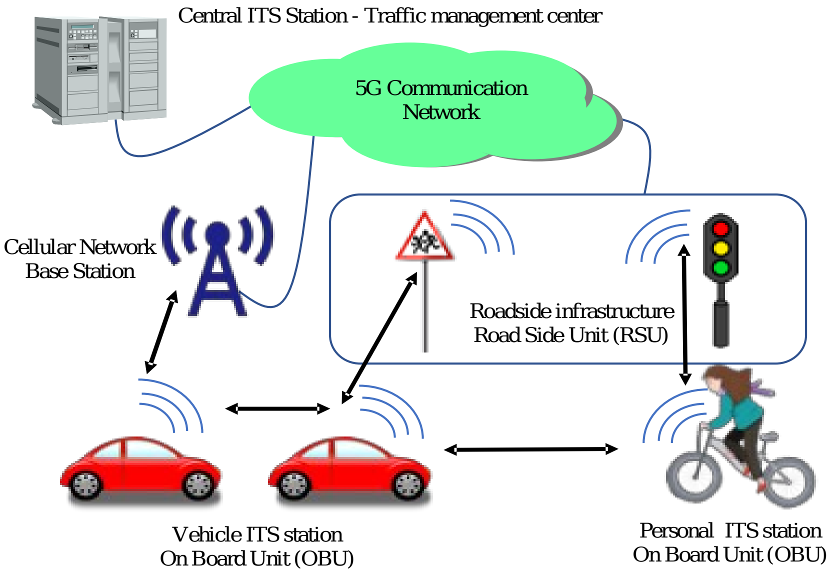
V2X Chipsets

- Commsignia, Cohda Wireless, Marven, Savari

Use case with open source softwar

- UPC, i2CAT, SEAT, Ficosa, Movistar, CTTC
- Vanetza
- Raspberry Pi 3





Positioning

- One highly critical point in C-ITS is positioning accuracy
- GNSS systems can not provide lane-accuracy
- Hybrid systems: sensor fusion
  - GNSS
  - Inertial sensors
  - Ultra Wide Band ranging
    - IEEE 802.15.4a